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Article

Indigenous Peoples and Local Communities' Perception and Lifestyle Compatible with Peatlands Conservation in the Lake Tumba Periphery, Équateur Province, Democratic Republic of Congo

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Abstract

The Congo Basin peatlands, the world's largest tropical peatland complex, critical for global carbon storage yet remain poorly understood from a human dimensions perspective. This study explores the perceptions, lifestyles, and knowledge systems of Indigenous Peoples and local communities around Lake Tumba, Democratic Republic of Congo, to identify practices supporting peatland conservation. Using a mixed-methods approach—household surveys (n = 320), focus groups, and statistical analyses including chi-square tests and Multiple Correspondence Analysis (MCA); the study reveals a predominantly Indigenous agrarian society with limited formal education and strong reliance on peatlands for food (93.7%), construction materials (79.0%), and medicines (75.9%). While regulating services such as carbon storage were seldom recognized, traditional ecological knowledge was evident in sacred species protection, ritual plant and animal uses, and intergenerational knowledge transfer, mainly father-to-son. However, 95.3% of respondents cited religion as the main barrier to this transmission. MCA confirmed that livelihoods, village status, and ritual practices form an integrated socio-cultural system aligned with conservation. These findings stress the role of endogenous governance in sustaining peatland-compatible lifestyles. Conservation efforts should move beyond carbon-centered or top-down approaches to reinforce land tenure, traditional governance, and knowledge transmission, thereby protecting both peatlands and the cultural identities sustaining them.

Keywords: Congo basin peatlands; indigenous peoples; local communities; traditional ecological knowledge; biocultural conservation; Lake Tumba; Democratic Republic of Congo

1. Introduction

Peatlands are rare but cover around 3-4% of the planet's land surface and contain up to one third of the world's soil carbon. This is twice the amount of carbon as found in the entirety of Earth's Forest biomass [1]. According to the latter, beyond the vast quantities of carbon that they slowly sequester and store, they provide a range of valuable additional benefits and services to humanity. Peatlands

provide livelihood opportunities to local communities and national economies. They are a source of food, medicines, timber, amenity, and domestic energy in some countries [2].

In Africa, the central Congo peatlands, spanning the Democratic Republic of the Congo (DRC) and the Republic of the Congo (ROC), are the world's largest tropical peatland complex [3]. The recent mapping of 167,600 km² of peat by [4], showed that they cover 16.8 million ha, storing approximately thirty billion metric tons of carbon, equivalent to 28% of Earth's tropical peat carbon stock [3,4]. Their immense areas of untouched rainforest, swamp forests, grasslands, floating prairies, seasonal lakes, ponds, and rivers account for the most biologically diverse wetland landscape in Africa. (<https://globalpeatlands.org/>, accessed on 16th August 2025). But they also appear to be vulnerable to climate change [5] and are under threat from changes in land use [6], including logging, industrial agriculture and oil exploration and exploitation [7]. The DRC's government recently auctioned oil exploitation titles in the Cuvette Centrale peatlands, showing that this region remain likely to face growing pressure soon [8].

Since the DRC submitted its Nationally Determined Contributions, committing to reduce its emissions by 17% by 2030 for the Paris Agreement in 2015, the country has come a long way in peatland action. Thus, peatland protection, restoration and sustainable management are nowhere to be found in the country's commitments, and is now developing a National Peatland Strategy (<https://globalpeatlands.org/>, accessed on 16th August 2025), including the consideration of local communities (LCs) and indigenous peoples (IPs).

Peatlands are well known to support the livelihoods of rural and Indigenous communities in the Congo Basin [9]. They hold social, economic, cultural, and spiritual value for many people who live in the Cuvette Centrale region [8], especially those communities that are heavily reliant on peatland ecosystem services. It is estimated that around 5.5 million people reside within a 10 km distance of the central Congo Basin peatland complex, of which 4.6 million reside in the DRC [10]. Peatlands are materially valuable to these people because they provide food, drinking water, wood and fiber for constructing houses and tools for harvesting peatland resources (e.g., fishing baskets), fuel wood and traditional medicine [9].

Human-focused research in peatlands is scarce in the DRC, mainly on the local practices favorable to their conservation. Research focuses mainly on the link between peatlands and carbon storage-climate change, but according to [7], the current impact of LCs on the peatland ecosystems is likely to be minor and relatively sustainable in its current form. People of Bantu origin make up the largest ethnic group in the Cuvette Centrale region and often lead a subsistence livelihood focused on fishing and small-scale farming of crops such as manioc (*Manihot esculenta*) and banana (*Musa* spp.), and limited numbers of livestock including goats and chickens [7]. This Bantu populations likely arrived in the region within the last 2000 years [11]; IPs hunter-gatherer groups have been present for much longer (possibly since as far back as 40,000 years [12]). This IPs, recognized as the original inhabitants of the DRC [13], number an estimated two million within forested areas [14]. Their cultures, belief systems, and subsistence strategies are deeply intertwined with forest ecosystems [15].

Thus, this study aimed to identify and analyze the IPs and LCs perception on their lifestyles and practices that are conducive to the Lake Tumba peatlands conservation. It specifically intended to identify the ecosystem services that IPs and LCs obtain from Lake Tumba peatlands landscape, to document the traditional practices and indigenous knowledge related to peatland conservation; and to identify the transmission pathways and the constraints that hinder both the application and the intergenerational transmission of such practices and knowledge.

2. Materials and Methods

2.1. Overview of the Study Area

Lake Tumba's periphery encompasses the peatland areas of Equateur Province, specifically within the Bikoro, Ingende, and Lukolela Territories (Figure 1). The lake Tumba is a residual lake of

500m2 located in the Eastern part of the province that has as capital the city of Mbandaka and comprises seven administrative territories: Basankusu, Bolomba, Bomongo, Bikoro, Ingende, Lukolela, and Mankanza (loi organique n° 15-006 du 25 mars 2015 portant fixation des limites des provinces et celle de la ville de Kinshasa). In the Équateur Province, annual precipitation ranges between 1,800- and 2,000-mm. Rainfall peaks occur in April and October, while the minimum precipitation is recorded in January and July [16].

The scope of the research was restricted to Bikoro and Ingende Territories. The Bikoro Territory covers 13,842² km area. It is bounded to the north by Mbandaka’s urban; to the east by the Ingende and Kiri territories in the Mai-Ndombe District; to the west by the Lukolela Territory; and to the south by the Inongo Territory, also in the Mai-Ndombe District. The Ingende Territory covers 17,328 km² area. It is bounded to the north by the Bolomba Territory; to the east by the Boende and Monkoto Territories in the Tshuapa District; to the south by the Kiri Territory in the Mai-Ndombe District; and to the west by the Bikoro Territory [17]. The various vegetation, soil types and hydrography are presented respectively in Tables 1 and 2.

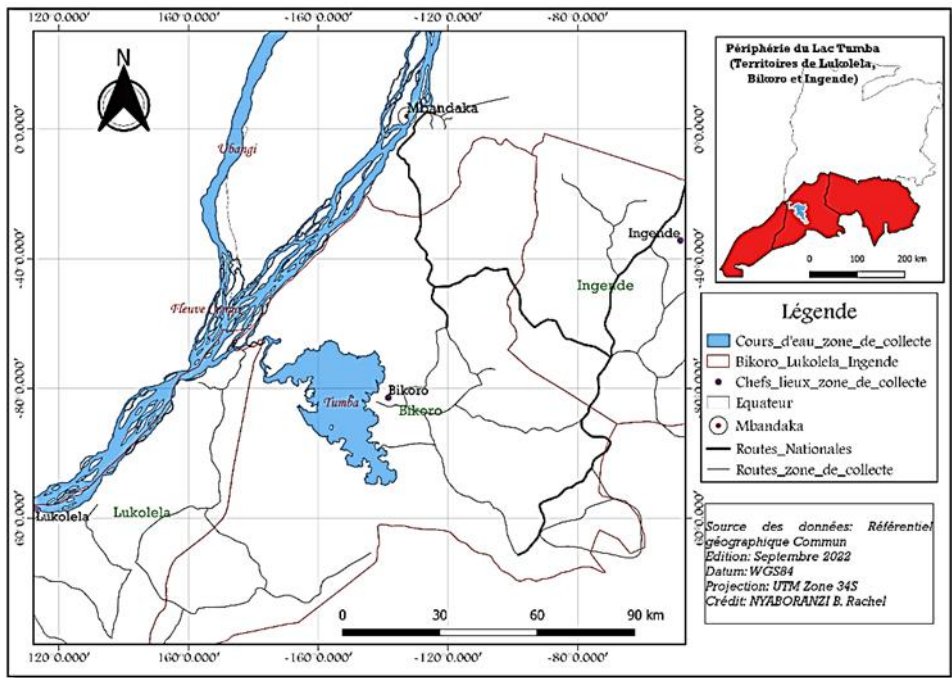


Figure 1. Location map of the study area.

Table 1. Distribution of the main vegetation types in the Equateur District compared to the national level (Vancutsem, 2009, Verheggen et al., 2010 in [17].

Vegetation type	Equateur		Equateur/DRC	DRC
	surface area (ha)	surface area (%)	surface area (%)	surface area (ha)
Dense rain forest	4 537 687	44.88	4.85	93 517 825
Forest on hydromorphic soil	4 768 070	47.15	31.40	15 183 214
Swampy vegetation	85 551	0.85	15.97	535 714
Shrub savannah	2 477	0.02	0.02	15 335 810
grassy savanna	57 084	0.56	0.38	14 881 257
Total natural vegetation	9 450 870	93.46	5.44	173 855 384
Permanent agriculture	1 421	0.01	0.09	1 555 849
Agricultural complex	659 449	6.52	1.23	53 576 845
Total anthropized area	660 870	6.54	0.38	55 132 694

Table 2. Hydrography and soil of Ingende and Bikoro territories [17].

Territory	Hydrography	Soil
Ingende	Ingende Territory is characterized by a hydrological network dominated by the Ruki River, which receives its main tributaries, the Momboyo and the Busira, before discharging into the Congo river; the Ingende town, the territorial administrative center, is situated at their confluence.	The soil in the region is moist and sandy-clayey. This soil’s type is conducive to the fruiting of the oil palm (<i>Elaeis guineensis</i>). This explains the presence of a large oil palm plantation in Boteka.
Bikoro	The Bikoro region’s hydrography is dominated by Lake Ntomba (surface area: 765 km²) in its western sector. Downstream of the lake, toward the Lukolela Territory (Irebu), significant watercourses are present, which frequently transform the area into vast wetlands (Lolo, Lolambo, Bituka, Boloko), along with (the smaller) Lake Mpaku, connected to the Ruki River.	The soil in the Bikoro region is characterized by a sandy-clay composition. This edaphic type is particularly suitable for slash-and-burn agricultural practices in the Ekonda and Elanga sectors. In the Lac sector, the soil frequently exhibits hydromorphic properties with wetland characteristics.

2.2. Methodological Strategy

2.2.1. Choice of Sites, Territories, Villages, and Sample Size

The choice of the Equateur Province is because it is located entirely within the Congolese Cuvette (central Congo peatlands), and a substantial portion of the territory consists of swampy areas and remains extensively inundated throughout the year, as mentioned by [17]. The choice of the Bikoro and Ingende Territories and not the Lukolela Territory was due to logistical constraints, particularly those related to the mobility difficulties to the Lukolela Territory. In addition, Bikoro occupies the most depressed part of the congolese Central Cuvette, where extensive swampy areas are found. Three key criteria guided the selection of villages for the survey: first, the presence of a peatland area (‘Entoku’) surrounding the village; second, the existence of Indigenous Pygmy communities within the villages; and third, ease of access to the villages.

2.2.2. Data Collection Technique

Both qualitative and quantitative data were collected directly on the field and through questionnaires administrated to households and focus groups. The unit used in this study is the household. The interviews were done in the morning and in the evening when the people had finished going about their daily tasks. The surveys were conducted in five sectors, including three in Bikoro (Elanga, Ekonda, and Lake Tomba) and two in Ingende (Bokatola and Duali). In total, 31 villages were concerned in the study. The number of questionnaires administered per village depends on the highest population distribution rate of the villages. The sample size was determined at around 5% level of precision. In total, 320 households on around 6400 (Table 3). The Following [18] formula was used to calculate the sample.

$$n = \frac{\frac{Z^2 X p (1 - p)}{e^2}}{1 + \left(\frac{Z^2 X p (1 - p)}{e^2 N} \right)}$$

where: n = size of the sample to be interviewed, Z = 1.96 (confidence level according to the reduced centered normal distribution), P = estimated proportion of the population which presents the desired characteristics (when unknown, we use P = 0.5), N = size of the population, e = 0.05 (range expressing the margin of error).

Table 3. Number of respondents by village, sector, and territory.

Territories	Sectors	Villages	Number of households	Total number
Ingende	Dwali	Ingende centre	27	150
		Boteka	20	
		Makako	20	
		Bofalamboka	20	
		Ntomba	20	
		Bofekalasumba	20	
		Ilambasa	20	
		Ingende	3	
	Bokatola	Bongongo	10	20
		Ilanga	10	
Total Ingende			170	
Bikoro	Lac Ntomba	Bikoro centre	20	80
		Ntondo	20	
		Moheli	10	
		Iyembe moke	10	
		Lokando	10	
		Mpabolia	9	
		Mpa bolia	1	
	Ekonda	Ikoko impenge	12	30
		Mekakalaka	8	
		Itipo	8	
		Ngeli alingo/maringo	1	
		Ngeli alingo	1	
	Elanga	Elanga	10	40
		Baolongo	10	
		Beambo	8	
		Lokolama	7	
		Penzele	3	
		Nkalamba	2	
	Total			150
General total			320	

- Sociodemographic data

Sociodemographic data were obtained through comprehensive surveys using a single semi-structured questionnaire. For the closed-ended questions, the Kobo Collect application was employed. Following rigorous verification, all data were systematically uploaded to the central server on Kobo toolbox, which was managed efficiently.
- Data on the integration of Indigenous knowledge

Ten-focus group discussions were organized, with an average of seven (07) participants per village. The members of this focus group were selected according to age (elderly, adults, and young people), gender (men and women), membership of hunting group, farmers’ organization, ethnic diversity, and the distribution between Indigenous and allochthones peoples. The themes addressed included the ecosystem services that IPs and LCs obtain from Lake Tumba peatlands landscape; the traditional practices and Indigenous knowledge related to peatland conservation (Traditional belief link to plants and animal species conservation); and intergenerational transmission of traditional knowledge and practices (transmission pathways and constraints).

2.2.3. Data Analysis

Data were processed using Microsoft Excel 2016, for the establishment of a raw field database and the production of graphs resulting from the descriptive analysis of data. R-Studio version 2025.05.01 and SPSS version 26 were used for data analysis.

The Chi-square test was employed to assess the dependence between the qualitative variables that constitute the core of this study (with the assumption that variables are independent, at the threshold of 5%). And the Multiple Correspondence Analysis (MCA) was used to establish the correlation between variables and to graphically represent the relationships between all of them and between individuals.

2.2.4. Ethics and Results Validation

To ensure scientific ethics and validate the findings of this research, the following measures were implemented:

- Free, prior, and informed consent was obtained from each participant.
- Results were returned to the communities for validation through participatory feedback;
- No protected species were destroyed or collected.

3. Results

3.1. Sociodemographic Characteristics of the Respondents

The surveyed population (Table 4) was predominantly male (88.12%), with women representing only 11.88%. IPs constituted the majority (85%), while non-Indigenous (Bantu) accounted for 15%. Educational attainment remained low: 41.25% were illiterate, 15% had completed primary school, 37.5% reached secondary education, and only 6.25% attained university level.

Age distribution indicated a relatively mature population, with 48.12% aged over 40 years, 46.25% between 26 and 40 years, and only 5.63% between 18 and 25 years. Most respondents were married (86.56%), confirming the importance of household and family structures.

Livelihoods were largely agrarian, with agriculture employing more than half of respondents (54.69%). Teaching (17.5%) and health services (6.56%) represented secondary activities, while trade (5.94%), fishing (4.69%), and administrative work (4.38%) were less common. Only marginal proportions reported involvement in civil service, logging, oil mill labor, or other specialized professions.

Overall, the data depict a male-dominated, predominantly Indigenous, and agriculturally oriented society with low levels of formal education and a mature age structure.

Table 4. Sociodemographic characteristics of the respondents.

Variable	Classification	Number	Proportion (%)
Sex	Women	38	11.88
	Men	282	88.12
Status in the village	Indigenous	272	85
	Non-Indigenous (Bantu)	48	15
Level of study	Illiterate	132	41.25
	Primary	48	15
	High school	120	37.5
	University	20	6.25
Age	18-25 years	18	5.63
	26-40 years	148	46.25
	>40 years	154	48.12
Marital status	Married	277	86.56
	Single	19	5.94

Main activity	Divorced	13	4.06
	Widow	11	3.44
	Agriculture	175	54.69
	Teacher	56	17.50
	Trade	19	5.94
	Health personnel	21	6.56
	Fishing	15	4.69
	Administration	14	4.38
	Civil service	4	1.25
	Pastor	1	0.31
	Hunting	2	0.63
	Livestock	1	0.31
	Study	5	1.56
	Work in the oil mill of Boteka	3	0.94
	Lawyer	1	0.31
	Logging	3	0.94

3.1.1. Seniority in the Practiced Activities

The distribution of respondents according to their seniority in the activity in Figure 2, reveals a marked heterogeneity across the sample. According to this figure, the largest subgroup reported 30 years of experience (n = 50; 15.6%), followed by 20 years (n = 33; 10.3%) and 35 years (n = 46; 14.4%). A considerable proportion of respondents also indicated shorter durations of involvement, such as one year (n = 50; 15.6%) or two years (n = 33; 10.3%), suggesting both the presence of newcomers and long-term practitioners within the activity. Intermediate categories (e.g., 15 years, n = 39; 25 years, n = 19; 10 years, n = 13) were less represented but nonetheless contribute to illustrating the diversity of experiences.

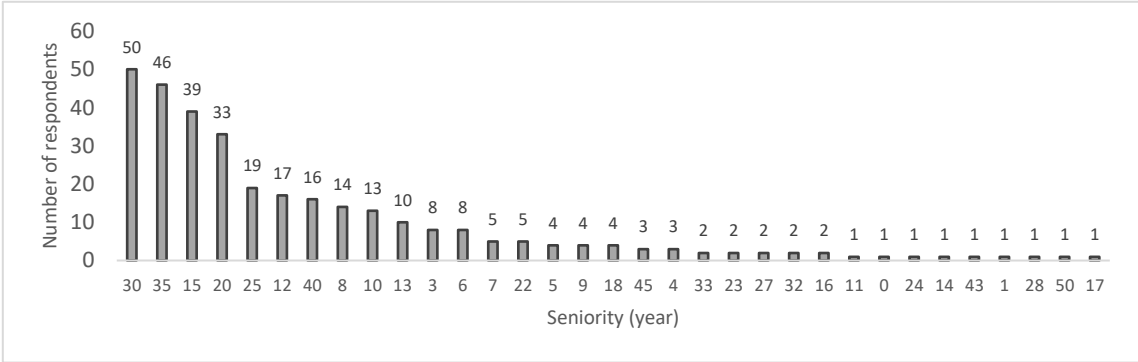


Figure 2. Distribution of Respondents by Seniority in the main activities.

3.2. Peatlands’ Ecosystem Services (ES) Mentioned by LCs and IPs

The results in Figure 3 indicate that peatlands are perceived by LCs and IPs as providing a wide array of ecosystem services, although their relative importance varies substantially. Among the provisioning services, food emerges as the most frequently cited benefit, reported by 93.7% of respondents. This is closely followed by construction materials (79.0%) and medicinal resources (75.9%), underscoring the centrality of peatland-derived products in sustaining daily subsistence and health needs. Firewood (46.2%) and other materials (40.9%) were mentioned less frequently but remain significant contributors to household livelihoods.

In contrast, regulating and cultural services were rarely acknowledged. Only two respondents (0.6%) identified ecotourism potential, while carbon storage, arguably the most critical global service provided by peatlands, was mentioned by a single respondent (0.3%). This striking discrepancy

reveals that local perceptions are overwhelmingly oriented towards tangible, immediate benefits, whereas globally recognized regulating services remain largely underappreciated within the surveyed communities.

Overall, the data highlights a strong dependence on peatlands for material subsistence, coupled with a limited awareness of their broader ecological functions.

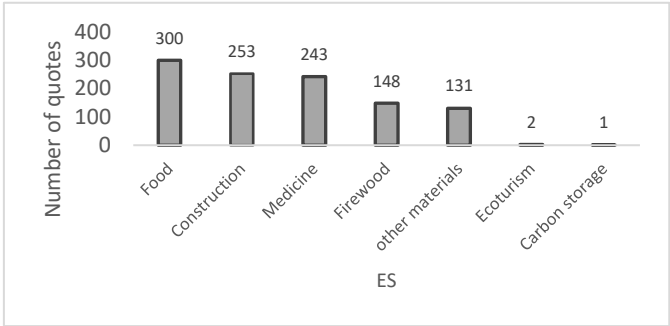


Figure 3. Ecosystem services provided by peatlands to LCs and IPs.

3.3. *Traditional Practices and Indigenous Knowledge Related to Peatland Conservation*

3.3.1. Traditional Perception/Belief Link to Plants and Animal Species Conservation

- Existence of plants and three species conserved for their special usage in yield increase.

The responses regarding the conservation of plant and tree species for enhancing yields in hunting, fishing, and agricultural activities indicate a strong indigenous’ belief of their functional importance. Figure 4 shows that most respondents (64.1%) reported that specific plant and tree species are deliberately conserved to enhance yields in hunting, fishing, and agricultural activities, reflecting the persistence of local ecological knowledge and practices that sustain subsistence systems. In contrast, 18.1% indicated that no such conservation practices occur, while 17.8% expressed uncertainty.

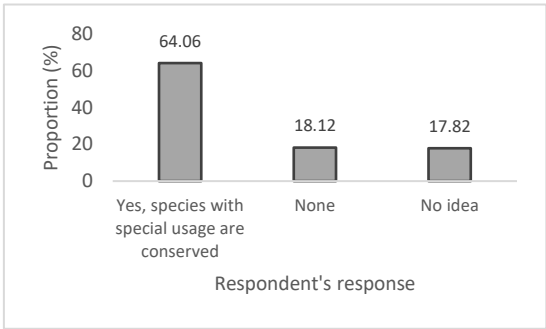


Figure 4. Existence of plants and three species conserved for their special usage in yield increase.

- Existence of sacred plants and trees prohibited from exploitation or consumption

According to Figure 5, a significant majority (84.37%) affirmed the existence of sacred species within their cultural or religious context. In contrast, a small minority of respondents (10.63%) reported that no such sacred or prohibited species exist. Finally, a negligible portion of the sample, 5.00%, expressed uncertainty (“No idea”) on the matter.

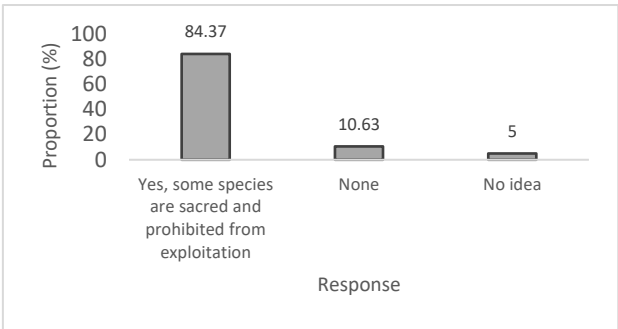


Figure 5. Existence of sacred plants and trees prohibited from exploitation or consumption.

- Existence of animals used in traditional rites and beliefs to increase yields in hunting, fishing and agricultural activities.

Figure 6 reveal an overwhelming reliance on domestic animals, with a commanding 88.12% of respondents indicating their exclusive use in such rituals. The use of wildlife exclusively is reported by a much smaller segment (7.5%), indicating that while present, rituals solely dependent on wild species are less common. A minimal proportion of respondents (2.5%) reported the use of both domestic and wildlife species, suggesting the existence of complex, hybrid rituals that potentially bridge the conceptual domains of the domestic/tamed and the wild/untamed to achieve comprehensive efficacy. Notably, the perspectives that no animals are used for this purpose or expressions of uncertainty (“No idea”) are statistically marginal, each constituting a mere 0.94% of the responses. The near absence of these categories signifies that the practice of using animals in yield-augmenting rites is universally acknowledged within the respondent pool, pointing to its status as a deeply ingrained and non-esoteric cultural norm.

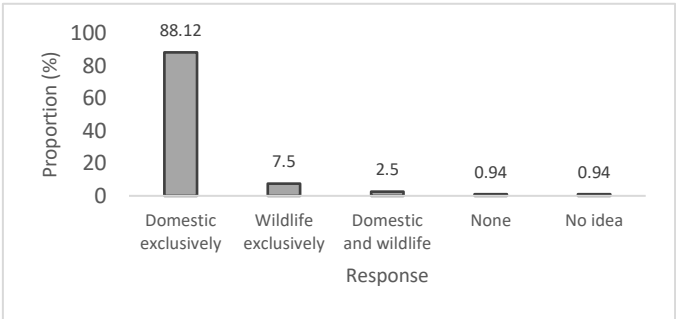


Figure 6. Animals used in traditional rite to increase yields.

3.4. Intergenerational transmission pathways of traditional knowledge and practices

Four principal pathways for the transmission of endogenous knowledge and practical skills were identified among LCs and IPs across the study area. These include father-to-son, mother-to-daughter, elder-to-youth, and intra-family transmission involving extended kin such as uncles, aunts, cousins, and grandparents. As illustrated in Figure 7, the dominant channel is father-to-son transmission (30.6%), followed closely by intra-family mechanisms (32.71%) that encompass intergenerational exchanges among younger relatives and close kin. Elder-to-youth transmission accounts for 20.87%, while mother-to-daughter pathways represent the smallest share (15.8%).

The timing of knowledge transmission is shaped by both the recipient’s age and the nature of the knowledge itself. Spiritual or magico-religious knowledge is generally restricted to young adults—regarded as adolescents within the local cultural context—who are considered trustworthy and are initiated through esoteric rituals, with the expectation that such knowledge remains strictly confidential. In contrast, knowledge essential for subsistence and collective well-being—such as foraging techniques, craftsmanship, agricultural practices, and the use of medicinal plants—is

transmitted from early childhood onward, primarily through observation, imitation, and active engagement in everyday activities.

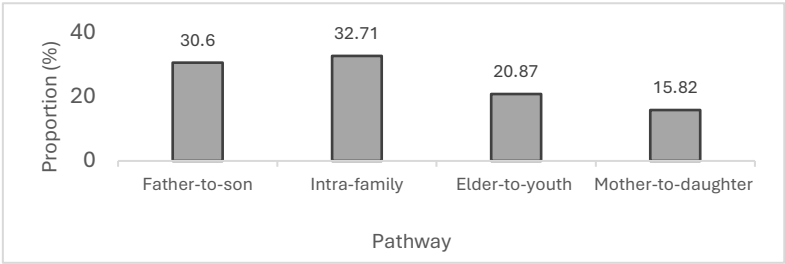


Figure 7. Intergenerational transmission pathways.

3.5. Constraints to the Intergenerational Transmission of Traditional Knowledge and Practices

The results in Figure 8 reveal a striking and overwhelming consensus on the primary impediment. An overwhelming majority of respondents, 95.31%, identified religion as the main constraint. This near-unanimous perception indicates that the introduction or dominance of external religious systems is not merely a contributing factor but is viewed as the principal agent disrupting the continuity of Indigenous knowledge systems. In stark contrast, modernity, a broad category encompassing factors such as formal education, urbanization, technological adoption, and shifting economic priorities; was perceived as a significant constraint by only 4.38% of respondents. The factor of cohabitation with non-Indigenous people (allochthones) is statistically marginal, cited by a mere 0.31% of respondents.

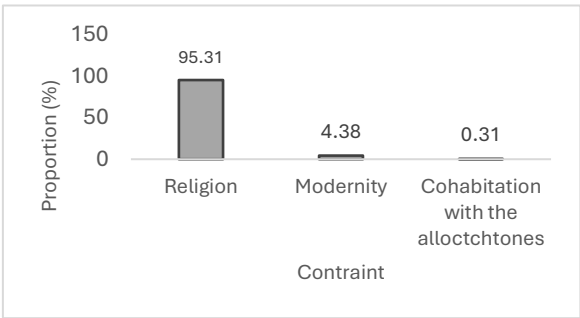


Figure 8. Constraints to the intergenerational transmission.

3.5.1. Associations Between the Variables and Among the Respondents

Overall, the matrix of Pearson chi-square tests indicates a patterned, non-random coupling between socio-demographic attributes, livelihood structure, and culturally embedded conservation practices in communities fringing the study area (Table 5). Several associations are consistently strong, especially those linking main activity (PA), village status (VS), and education level (LS) to indicators of sacred/ritual use of biota and to reported constraint ; while others (e.g., with the composite ecosystem services (ES) variable) are largely null.

Table 5. Association between variables.

	VS	MS	LS	PA	PEW	PEP	ES	SP	PUR	AUR	Const
SEX	4.1265 *	10.22 *	3.0654 Ns	128.85 **	1.89 10-30 Ns	7.5381 *	0.90717 Ns	7.7557 *	52.774 **	3.3942 Ns	0.37881 Ns
VS	-	9.6102 *	41.988 **	145.43 **	0.15785 Ns	7.3409 *	0.18961 Ns	85.751 **	62.764 **	11.902 **	9.0591 *
MS	-	-	14.074 Ns	175.35 **	0.31242 Ns	2.6145 Ns	3.4747 Ns	10.314 Ns	13.053 Ns	7.4972 Ns	3.1537 Ns

LS	-	-	385.14 **	3.3543 Ns	11.669 Ns	3.5414 Ns	22.218 **	21.023 **	14.201 **	4.7081 Ns
PA	-	-	--	96.38 **	200.89 **	47.019 Ns	200.15 **	157.05 **	403.39 *	126.54 **
PEW	-	-	-	-	11.934 **	0.04501 Ns	9.3153 **	1.7431 Ns	0.031946 Ns	10.016 **
PEP	-	-	-	-	-	28.765 **	4.7013 Ns	11.187, *	7.4564 Ns	4.694 Ns
ES	-	-	-	-	-	-	0.67882 Ns	4.8929 Ns	0.1136 Ns	55.012 **
SP	-	-	-	-	-	-	-	66.834 **	15.207 **	0.61246 Ns
PUR	-	-	-	-	-	-	-	-	22.945 **	7.7582 Ns
AUR	-	-	-	-	-	-	-	-	-	64.00Ns

Legend: * = significant *p*-value < 0.05 ; ** = significant *p*-value < 0.01 ; Ns = non-significant *p*-value > 0.05 ; Sex = gender; VS = village status ; MS = marital status ; LS = level of study ; PA = main activity; PEW = presence of endemic wildlife ; PEP = presence of endemic plants ; ES = ecosystem services; SP = sacred plants prohibited from harvest or consumption ; PUR = plants used in traditional rituals ; AUR = animals used in traditional rituals ; Const = constraints.

• Socio-demographics and livelihoods

Gender shows significant associations with village status, marital status, main activity, presence of endemic plants, sacred plants, and plants used in rituals (e.g., χ^2 with PA: 128.85, $p < 0.01$), suggesting gendered access to or roles in livelihood and biocultural domains; links with education, ecosystem services, animals used in rituals, and constraints are non-significant. This pattern points to gendered specialization in plant-based cultural practices rather than uniform gender effects across all conservation-relevant dimensions. Village status is associated with marital status, education, main activity, and all three ritual/sacred indicators (SP, PUR, AUR), as well as with constraints. The strength of these links (e.g., VS–PA: $\chi^2=145.43$, $p < 0.01$; VS–SP: $\chi^2=85.75$, $p < 0.01$) implies spatially structured social organization and biocultural practice that could mediate conservation outcomes at the village

scale. Education level is tightly linked to main activity and to the three cultural-use indicators (SP, PUR, AUR), but not to ecosystem services or constraints. The signal (e.g., LS–PA: $\chi^2=385.14$, $p < 0.01$) is consistent with education sorting individuals into distinct livelihood niches, which in turn align with specific cultural engagements with flora and fauna. Marital status relates strongly to main activity ($\chi^2=175.35$, $p < 0.01$) but not to most other domains, indicating household formation affects livelihood positioning more than it does culturally protected or ritual uses per se.

• Livelihoods, biocultural practice, and biodiversity presence

Main activity (PA) exhibits the broadest, most robust association profile: it is significantly related to presence of endemic wildlife and endemic plants, to sacred plants, plants used in rituals, animals used in rituals, and to constraints (e.g., PA–AUR: $\chi^2=403.39$, $p < 0.05$; PA–PEP: $\chi^2=200.89$, $p < 0.01$). This points to livelihood choice as a central pathway coupling human behavior to both biodiversity encounters and biocultural practice, an important lever for conservation planning. Signals for biodiversity presence of endemic wildlife (PEW) is associated with sacred plants and constraints, but not with ecosystem services; presence of endemic plants (PEP) associated with ecosystem services and plants used in rituals, but not with sacred plants or animals used in rituals. These contrasts suggest different perceptual and cultural pathways by which plant versus animal endemism is integrated into local institutions and use regimes.

• Cultural safeguards and constraints

The three cultural indicators are themselves strongly inter-correlated: sacred plants (SP) co-vary with plants used in rituals (PUR) and animals used in rituals (AUR); PUR is also associated with

AUR. The magnitude of these links (e.g., SP–PUR: $\chi^2=66.83$, $p<0.01$; PUR–AUR: $\chi^2=22.95$, $p<0.01$) is consistent with an integrated biocultural complex wherein sacred designation, ritual use, and animal symbolism cohere as a mutually reinforcing system. Constraints are most tightly linked to animals used in rituals (AUR) ($\chi^2=640$, $p<0.01$) and to ecosystem services (ES) ($\chi^2=55.01$, $p<0.01$), with additional connections to village status and main activity. This pattern implies that where ritual animal use is salient; or where communities report higher ES; people also face stronger constraints.

• Non-associations (informative nulls)

The near-absence of significant links with the composite ecosystem services (ES) variable, except for its association with constraints and with presence of endemic plants (PEP), suggests either (i) coarse measurement/aggregation of ES masking finer gradients, or (ii) that ES perceptions are weakly structured by the socio-demographic and ritual variables considered. Such nulls sharpen the conclusion that biocultural practice and livelihood position, rather than generalized ES perceptions, are the primary axes aligning with conservation-relevant behaviors here.

The Multiple Correspondence Analysis (MCA) yielded a coherent factorial structure with acceptable internal consistency (Table 6). The first two dimensions together explained 44.9% of the total variance (25.9% and 19.0% respectively), indicating that they capture the major patterns of association among the categorical variables under study. Cronbach’s alpha values for Dimension 1 (0.740) and Dimension 2 (0.614) further suggest satisfactory reliability of the constructs.

Table 6. Summary of models.

Dimension	Cronbach’s alpha	Represented variance		
		Total (eigenvalue)	Inertia	% of the variance
1	0.740	3.108	0.259	25.897
2	0.614	2.285	0.190	19.044
Total		5.393	0.449	
Mean	0.686a	2.696	0.225	22.470

a: The Cronbach alpha means is based on the mean eigenvalue.

Figure 9 depicts the distribution of the variables in relation to the two principal dimensions. Dimension 1 is primarily structured around sociodemographic and livelihood-related variables, notably main activity (PA), village status (VS), level of education (LS), and gender (Sex). These variables show strong positive associations with the presence of plants used in rituals (PUR), sacred plants (SP), and animals used in rituals (AUR). This suggests that livelihood orientation and sociocultural embeddedness are closely tied to traditional ecological knowledge and ritual practices.

Dimension 2, in contrast, is shaped by the intersection of cultural-ecological values and biodiversity-related indicators, such as the presence of endemic plants (PEP), presence of endemic wildlife (PEW), and recognition of ecosystem services (ES). Although the correlations are weaker than Dimension 1, this axis highlights how community perceptions of endemic species and spiritual prohibitions interact with broader socioecological practices.

Figure 10, illustrating the distribution of individuals according to their perceptions, exhibits a pattern consistent with that observed for the variables. Notably, certain individuals (27, 178, 318, and 319) exhibit response tendencies that substantially diverge from the means.

Figure 11 illustrates how variables cluster and contribute to the two main axes. Dimension 1 (horizontal axis) represents socioeconomic factors and ritual practices (main activity, village status, education, gender, ritual plants, and animals). The horizontal axis (Dimension 1; 25.9% of variance) reflects socioeconomic and ritual practices, while the vertical axis (Dimension 2; 19.0% of variance) captures ecological and cultural values. Three thematic clusters emerge: (i) Livelihood & Social Structure (light blue), grouping variables related to main activity, village status, education, and gender; (ii) Ritual Knowledge (lavender), including the use of ritual plants, sacred plants, and ritual animals; and (iii) Biodiversity & Sacred Values (green), encompassing perceptions of endemic plants,

endemic wildlife, and ecosystem services. Clustering underscores the strong interconnections between traditional ecological knowledge, social organization, and biodiversity conservation in peatland-dependent communities.

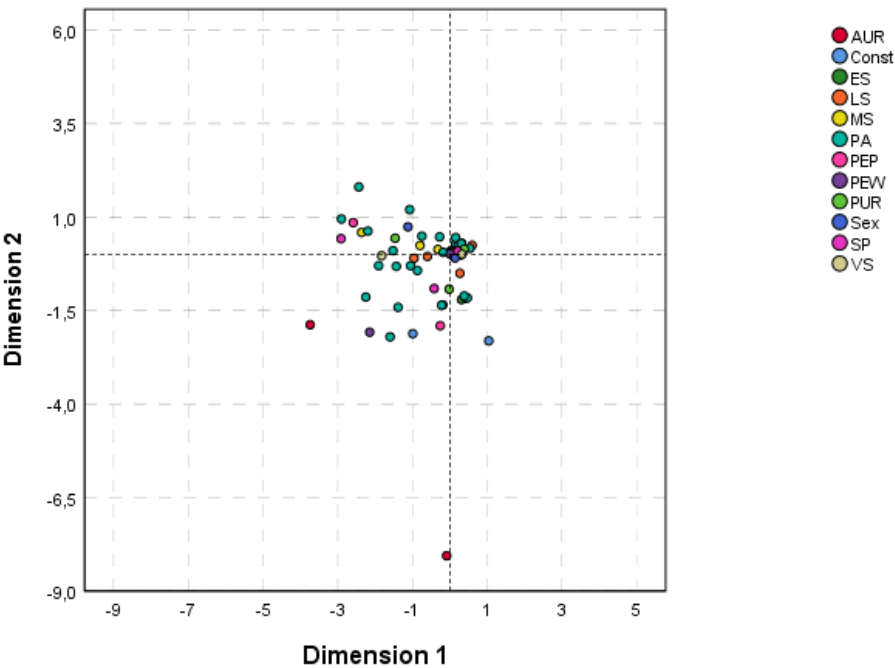


Figure 9. Plot of category points. With Sex = gender; VS = Village status ; MS = Marital status ; LS = level of study ; PA = main activity; PEW = Presence of endemic wildlife ; PEP =Presence of endemic plants ; ES = ecosystem services; SP = Sacred plants prohibited from harvest or consumption ; PUR = plants used in traditional rituals ; AUR = Animals used in traditional rituals.

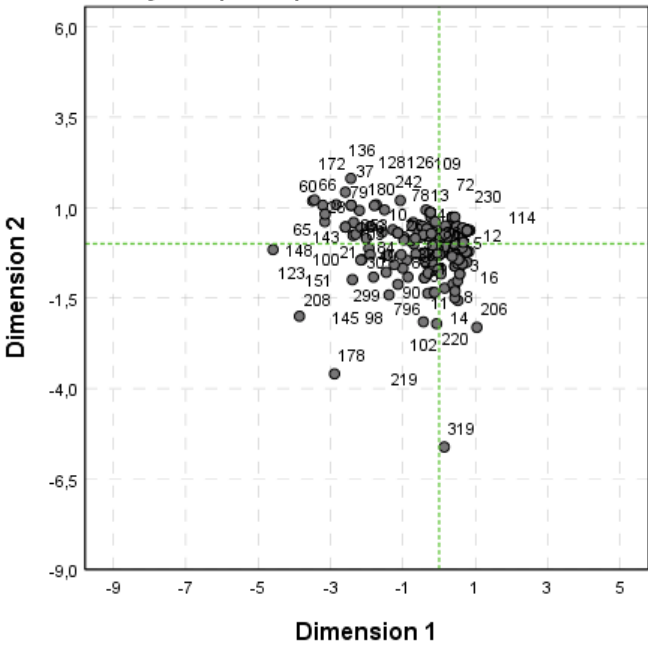


Figure 10. Object points corresponding to the 320 observations.

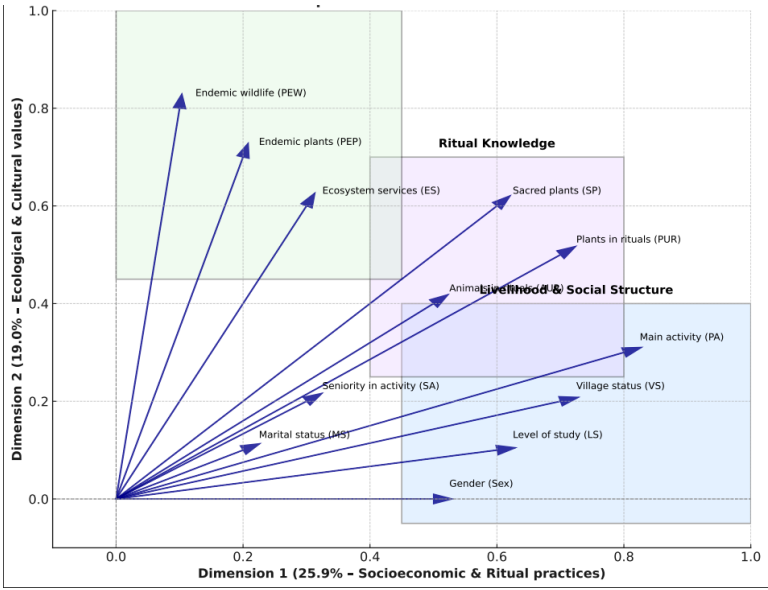


Figure 11. Thematic representation of the first two dimensions of the Multiple Correspondence Analysis (MCA).

Overall, the MCA results reveal that traditional knowledge systems, livelihood practices, and biodiversity perceptions are deeply interwoven. Communities whose main activities are subsistence-based and embedded in strong village structures are more likely to retain ritual uses of plants and animals, and to uphold taboos on sacred species. Conversely, formal education and marital status show weaker contributions, indicating that cultural identity and ecological embedding outweigh purely individual attributes in shaping peatland-compatible lifestyles.

From a conservation perspective, these findings underscore the importance of integrating ritual-ecological practices and community social organization into peatland management strategies. The preservation of sacred plants and ritual knowledge functions as a form of endogenous regulation of resource use, thereby aligning cultural continuity with biodiversity conservation goals.

4. Discussion

The findings of this study show that by centering the perceptions, knowledge systems, and practices of IPs and LCs in the Lake Tumba periphery, the research moves beyond the predominant biophysical and carbon-centric narratives [3,4] to illuminate the socio-cultural fabric that underpins human-peatland coexistence. The findings reveal a complex dynamic where deeply embedded traditional knowledge systems support a lifestyle largely compatible with conservation, yet these very systems face profound threats from external socio-cultural pressures.

4.1. Material Subsistence and the Perception Gap in Ecosystem Services

The overwhelming community focus on provisioning services as food, construction materials, and medicine; aligns with global studies on how rural and Indigenous communities perceive and value ecosystems primarily through direct utilitarian benefits [19]. This underscores the fundamental role of peatlands in ensuring food security, health, and shelter for these populations [8,9]. The near-total absence of recognition for regulating services, particularly carbon storage, is a critical finding. It highlights a significant perceptual disconnect between local and global values. While the international community rightly prioritizes the Congo peatlands as a carbon vault of global importance [1], local priorities are understandably oriented towards immediate daily survival. This dissonance presents a major challenge for designing conservation initiatives. Policies that focus solely on carbon credits without addressing local subsistence needs are likely to fail or even exacerbate

poverty [20]. Effective strategies must therefore integrate climate objectives with programs that secure and enhance the provision of these vital local ecosystem services.

4.2. *Endogenous Conservation Mechanisms: Ritual, Taboo, and Traditional Knowledge*

The study powerfully documents the existence of sophisticated endogenous conservation mechanisms. The widespread practice of conserving specific plant and tree species to enhance yields and the prevalence of sacred species prohibited from exploitation are not merely cultural artifacts; they function as de facto conservation protocols. This finding resonates with a growing body of literature on how traditional ecological knowledge and belief systems can effectively regulate resource use and maintain biodiversity [21,22]. The ritual use of animals, predominantly domestic, further suggests a cultural model that minimizes pressure on wild species while integrating livelihood practices into a spiritual framework. These practices align with the concept of “conservation by customary use,” where cultural norms ensure sustainability [23].

The Multiple Correspondence Analysis (MCA) robustly confirms that these practices are not isolated but are structurally embedded within the socio-economic and cultural organization of the communities. The strong clustering of main activity (subsistence agriculture), village status (indigenous identity), and the use of ritual and sacred plants, indicates that a traditional, land-based livelihood is the primary vehicle for maintaining this conservation-relevant knowledge. This suggests that any shift away from such livelihoods could erode these protective cultural practices.

4.3. *Intergenerational Transmission Pathways of Traditional Knowledge and Practices*

The findings on the intergenerational transmission of traditional knowledge and practices reveal a sophisticated, yet vulnerable, socio-cultural system that is fundamental to the perpetuation of a peatland-compatible lifestyle. The identified pathways, primarily father-to-son, intra-family, elder-to-youth, and mother-to-daughter, are not merely channels of information transfer; they represent the very scaffolding upon which cultural identity and ecological wisdom are built and sustained across generations [24]. This structure ensures that knowledge is not acquired in a vacuum but is deeply embedded within social relationships, responsibilities, and worldviews.

The observed gendered and age-specific dimensions of knowledge transmission are of particular significance. The dominance of father-to-son and intra-family transmission for knowledge related to hunting, fishing, and ritual practices reflects a common pattern in many indigenous societies where specific domains of knowledge are gendered [25]. Similarly, the mother-to-daughter pathway, though less represented in this survey, is crucial for the transmission of knowledge related to plant gathering, small-scale agriculture, and likely, domestic medicine and childcare, which are essential for household subsistence [26]. The critical role of elders underscores their status as living libraries of biocultural knowledge. Their involvement ensures the transfer of not only practical skills but also the historical context, ethical frameworks, and spiritual understandings that give meaning to those practices [21].

Furthermore, the distinction in the timing of transmission based on the nature of the knowledge is a sophisticated cultural adaptation. The early childhood initiation into subsistence knowledge through observation and imitation aligns with theories of situated learning, where knowledge is co-constructed through active participation in a “community of practice” [27]. This method ensures the seamless integration of practical skills into daily life. In stark contrast, the restriction of esoteric or spiritual knowledge to trusted young adults, bound by confidentiality, serves as a protective mechanism. It safeguards culturally sensitive and powerful knowledge from misuse, ensuring its integrity and preserving its potency within the appropriate ritual context [28]. This careful curation of knowledge demonstrates a deep understanding of its varying values and risks.

4.4. *Disruption of Intergenerational Transmission*

The most striking and alarming finding is the identification of external religion as the primary constraint to the intergenerational transmission of knowledge. This suggests that introduced religious doctrines may actively discourage or devalue traditional beliefs and practices, severing the cultural thread that connects generations. This is a more acute threat than broader forces of “modernity”, such as formal education or new technologies. This finding is consistent with studies elsewhere that show how missionary activities, and religious conversion can lead to the erosion of Indigenous languages, knowledge, and cultural identities [29]. The marginal role attributed to cohabitation with non-Indigenous people (Bantu) implies that the threat is not simply one of cultural contact, but rather of cultural substitution driven by specific ideological systems.

This erosion of transmission pathways threatens the long-term resilience of both the cultural systems and the peatland ecosystem they help protect. Knowledge that is not transmitted is knowledge lost. The loss of taboos on sacred species, for instance, could lead to their overexploitation, while the loss of ritual practices could disrupt the cultural frameworks that promote sustainable harvesting.

4.5. Overall Pattern of Associations Between the Variables

The overall pattern of results indicates that socio-demographic variables, livelihood structures, and biocultural practices are non-randomly and systematically intertwined in the Lake Tumba peatland periphery [30,31]. Significant associations between main activity (PA), village status (VS), and education level (LS) with ritualized uses of plants and animals, as well as with reported constraints, suggest that local conservation logics are deeply embedded in both livelihood practices and cultural institutions as mentioned by [23] and [32]. These findings are consistent with evidence that Indigenous and local communities maintain complex socio-ecological systems in which livelihood strategies, ritual traditions, and customary institutions jointly shape resource governance and biodiversity outcomes [30,31].

The strength of associations involving main activity underscores the centrality of livelihood specialization as a structuring force [33,34]. Hunters, fishers, and plant gatherers interact with peatland ecosystems in distinct ways, producing differentiated cultural prohibitions and uses [30]. Similar patterns have been documented across tropical forest frontiers by [33] and [34], where livelihood niches correspond to contrasting ecological knowledge systems and management practices. This highlights the need for livelihood-specific conservation strategies rather than generalized approaches to IPs and LCs engagement [35].

The role of village status indicates that conservation practices and constraints are not solely individual but also institutionally mediated at the collective level [36,37]. Village-level authorities and customary institutions structure the recognition and enforcement of sacred species, ritual taboos, and access rules [23]. Comparable findings have been reported in Amazonian and Melanesian contexts, where community identity and spatial organization shape both sacred geographies and conservation outcomes [36,37]. This underscores the importance of governance approaches that explicitly incorporate village-scale co-management mechanisms recognizing the legitimacy of local institutions [38].

The significant, though comparatively moderate, role of education level suggests that formal schooling differentiates livelihood positioning and ritual participation but exerts a weaker influence on broader ecosystem perceptions [35,39]. This aligns with studies showing that education can alter occupational pathways and cultural roles without necessarily eroding biocultural traditions [35,39]. Therefore, conservation education initiatives should be designed to reinforce, rather than replace, traditional knowledge transmission [30].

The absence of strong associations with the composite ecosystem services variable is equally noteworthy [40,41]. It suggests that generalized ES perceptions may be less salient locally than biocultural practices and livelihood imperatives [30]. This observation echoes critiques of the ecosystem services framework when applied to IPs and LCs contexts, where local categories of value are often expressed through ritual, kinship, and customary institutions rather than abstract service

typologies [40,41]. Consequently, conservation programs in peatland landscapes should prioritize biocultural framing over generic ES narratives to resonate with community logics [38,42].

Finally, the consistent associations between ritual uses of plants and animals and reported constraints highlight the dual role of culture as both a conservation asset and a site of contestation [23,32]. Ritual taboos and prohibitions often safeguard biodiversity [23,32], but they may also intersect with scarcity signals and external restrictions, generating tensions that undermine compliance [30,31]. This underscores the importance of co-designed management regimes that legitimize local ritual practices while establishing ecologically sustainable harvest limits [38,42].

Collectively, these findings suggest that in the Lake Tumba peatlands, conservation outcomes are most likely to be optimized not by imposing external frameworks but by aligning with existing livelihood niches, village institutions, and biocultural traditions as mentioned by [30,38,42]. Such approaches resonate with the concept of biocultural conservation, which emphasizes the interdependence of cultural and biological diversity and the crucial role of IPs and LCs governance systems in sustaining both [38,42].

5. Conclusions

This study shows that the lifestyles, perceptions, and knowledge systems of Indigenous Peoples and local communities (IPLCs) around Lake Tumba are historically aligned with peatland conservation. Their reliance on provisioning services—food, medicine, fuelwood, and construction materials—demonstrates a deep dependence on peatlands for subsistence, while rituals, taboos, and intergenerational knowledge transfer act as culturally embedded governance systems regulating resource use. These endogenous mechanisms function as *de facto* conservation practices, even without formal frameworks. However, this system is increasingly vulnerable. The primary threat is not economic exploitation alone, but the erosion of cultural continuity and knowledge transfer under external religious influences and broader socio-cultural change. Such disruptions risk dismantling practices that have safeguarded peatlands for generations.

From a policy standpoint, effective conservation requires integrating traditional ecological knowledge and cultural institutions into national peatland strategies. Carbon-centered or exclusionary approaches risk undermining local systems, while community-based, culturally sensitive strategies that secure land tenure, legitimize Indigenous governance, and support intergenerational transmission are indispensable.

Ultimately, the long-term protection of Congo Basin peatlands cannot be separated from the survival of the cultures that inhabit them. Sustainable management depends on reinforcing this interdependence and positioning biocultural diversity at the core of conservation and climate action.

6. Recommendations

The findings carry profound implications for the DRC's developing National Peatland Strategy. The study argues convincingly that a top-down, exclusionary conservation model would be both ethically problematic and ineffective in this context. Instead, a community-based, culturally sensitive approach is essential. It is necessary to:

- Integrate traditional and Indigenous knowledge into Management Plans: Conservation strategies must actively document, respect, and integrate the existing traditional knowledge and practices that are compatible with peatland health. This includes recognizing and legally supporting community-based governance systems that enforce taboos and sustainable practices.
- Bridge the perception gap: Conservation education and outreach programs must be designed to explain the global importance of carbon storage and other regulating services in the context of local benefits. Demonstrating how intact peatlands ensure clean water, stable fish stocks, and flood prevention can align local and global interests [43].
- Safeguard cultural transmission: Addressing the threat to knowledge transmission is perhaps the most complex challenge. Engaging with religious leaders to foster dialogue and find

synergies between faith and environmental stewardship could be a potential pathway. Furthermore, supporting informal, community-led education where elders teach the young within their cultural framework is crucial.

- Secure land tenure: The strong link between Indigenous village status and conservation-oriented practices underscores the importance of securing land and resource rights for IPs and LCs. Secure tenure provides the stability needed for communities to continue their traditional stewardship practices [44].

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