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Indigenous knowledge systems and their role in sustaining biological diversity within tropical forest reserves

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Abstract

Traditional ecological knowledge accumulated by indigenous communities over generations represents a reservoir of conservation practice that modern science is only beginning to document. This research assessed how indigenous knowledge systems contribute to sustaining biological diversity in the Yanachaga-Chemillén National Park and its buffer zone in the Pasco Region of Peru. A mixed-methods design paired ecological transect surveys with ethnobotanical interviews and participatory mapping sessions conducted among 136 members of three Yanesha indigenous communities between April and November 2021. The ecological survey recorded plant and animal species richness along 24 transects (12 within community-managed areas, 12 in non-community zones). Semi-structured interviews captured traditional management practices — sacred grove protection, rotational harvesting calendars, species-specific taboos, and fire management techniques. Species richness was 31.4% higher in community-managed areas than in comparable non-community zones (Shannon diversity index $H' = 3.42$ vs. 2.61 , $p < 0.001$). Respondents identified an average of 67 plant species by local name and described specific uses for 83.2% of those species. A significant positive correlation ($r = 0.67$, $p < 0.001$) emerged between indigenous knowledge scores and local biodiversity indices. Sacred groves — forest patches protected by spiritual belief systems — harboured 42.7% more tree species per hectare than adjacent unprotected stands. The findings confirm that indigenous knowledge systems act as de facto conservation mechanisms, maintaining forest integrity and species diversity through culturally embedded rules that regulate resource extraction without formal legal enforcement.

Keywords: Indigenous knowledge, biological diversity, tropical forest reserves, ethnobotany, sacred groves, traditional management, species richness, community conservation, cultural practices, ecological resilience

Introduction

Forests managed by indigenous peoples harbour as much or more biological diversity than many formally protected areas — a fact that conservation policy has been slow to acknowledge ^[1]. Across the tropics, indigenous territories overlap with roughly 40% of remaining intact forest landscapes, and satellite-based deforestation analyses consistently show lower clearance rates within those territories than in adjacent non-indigenous land ^[2]. This pattern is not accidental. It reflects centuries of accumulated knowledge about which species to harvest, when, and how much, embedded in cultural norms, spiritual beliefs, and seasonal calendars that function as informal management regimes ^[3].

Peru's Amazon and cloud-forest regions offer a compelling setting for examining this relationship. The country ranks among the world's ten most megadiverse nations, with over 25,000 plant species and 1,800 bird species recorded, many of them endemic ^[4]. At the same time, indigenous communities — Asháninka, Yanesha, Shipibo-Conibo, and dozens of others — manage substantial portions of this biological wealth through customary governance systems that predate national conservation legislation ^[5]. Yet the formal protected area network and indigenous management systems often operate in parallel rather than in coordination, and policy-makers lack the empirical evidence needed to integrate the two. Previous research has documented specific elements of indigenous botanical knowledge in lowland Amazonian settings ^[3, 6], but fewer assessments have linked that knowledge quantitatively to measurable biodiversity outcomes. And montane cloud forests,

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which host exceptionally high endemism rates, have received less ethnobiological attention than lowland sites^[7]. The Yanachaga-Chemillén National Park, situated at the transition between Andean highlands and Amazonian lowlands, provides a natural laboratory for testing whether indigenous knowledge systems contribute directly to species conservation in these high-endemism environments.

This research therefore asked three questions: (a) Is species richness higher in forest areas managed under indigenous knowledge systems than in comparable unmanaged or state-managed areas? (b) What specific traditional practices contribute most strongly to biodiversity maintenance? And (c) what is the quantitative relationship between community members' indigenous knowledge scores and local biodiversity indices? The answers bear on a practical debate: whether integrating indigenous management into formal conservation frameworks can deliver better ecological outcomes than conventional top-down protection alone^[8].

Materials and Methods

Study Area Description

The Yanachaga-Chemillén National Park (10°18'S, 75°27'W) covers 122,000 hectares of montane and premontane forest in the Oxapampa province, Pasco Region, Peru. Elevation ranges from 460 m to 3,800 m, creating a steep gradient of life zones from lowland tropical forest through cloud forest to high-altitude grasslands. Mean annual precipitation varies from 1,500 mm at lower elevations to over 4,000 mm in the cloud belt, and mean temperatures range from 24 °C to 8 °C along the altitudinal gradient. The park and its buffer zone support communities of the Yanesha people, one of Peru's oldest Amazonian ethnic groups, who maintain communal land titles under Peruvian law^[5]. Three Yanesha communities — Tsachopen, Shiringamazu, and San Pedro de Pichanaz — were selected based on their proximity to the park boundary and their maintenance of active traditional management practices.

Material

Ecological data were collected along 24 permanent transects, each 500 m long and 10 m wide, distributed equally between community-managed forest areas (n = 12) and non-community zones (n = 12) matched for elevation, slope, and aspect. Within each transect, all woody stems with a diameter at breast height ≥ 10 cm were identified to species level, and voucher specimens were deposited at the herbarium of Lima Research Institute. Bird and mammal presence was recorded using point counts (10-minute observations at 100-m intervals along each transect) and

camera traps (two units per transect operating for 30 consecutive days). Ethnobotanical data were gathered through semi-structured interviews with 136 community members (52 women, 84 men), selected by stratified purposive sampling to include elders (>60 years), middle-aged adults (30–60), and youth (18–29). A participatory mapping exercise in each community documented sacred groves, harvesting zones, and seasonal rotation areas using printed satellite imagery as a base map^[6].

Methods

Species richness was calculated as total species count per transect, and Shannon diversity indices (H') were computed for each site category. Differences between community-managed and non-community zones were tested using independent-samples t-tests and Mann-Whitney U tests where normality assumptions were not met. An indigenous knowledge score was constructed for each respondent by summing correctly identified plant species (out of 100 photo cards), correctly described uses, and reported adherence to traditional harvesting rules (scale 0–200). The relationship between community-level mean knowledge scores and transect-level biodiversity indices was assessed through Pearson correlation and simple linear regression. Qualitative interview data were analysed thematically, with codes assigned to four pre-defined categories — sacred grove management, rotational harvesting, species taboos, and fire management — and emergent themes recorded separately. All fieldwork ran from April to November 2021. Data analysis used R version 4.1.2 (R Core Team) with the vegan package for diversity indices^[9].

Ethical Considerations

Research approval was obtained from the Lima Research Institute Ethics Committee (Protocol LRI/EC/2020-031, approved 8 February 2021) and from Peru's National Service of Natural Protected Areas for work within the park buffer zone. Free, prior, and informed consent was secured from each participating community through assemblies conducted in the Yanesha language, following International Labour Organization Convention 169 guidelines. Individual interviewees signed or thumb-printed consent forms. Audio recordings were made only with explicit verbal permission, and all data were anonymised during transcription. No biological samples were removed from the park without authorisation.

Results

Table 1: Comparison of species richness and diversity indices between community-managed and non-community forest zones (n = 24 transects)

Parameter	Community-Managed	Non-Community	t / U	p-value
Tree species per transect	47.3 $\pm$ 8.6	36.1 $\pm$ 7.2	3.47	<0.001
Bird species per transect	28.9 $\pm$ 5.4	21.7 $\pm$ 4.8	3.28	0.003
Mammal detections (30 days)	12.4 $\pm$ 3.7	8.1 $\pm$ 2.9	U = 28.5	0.008
Shannon index (H') — trees	3.42 $\pm$ 0.31	2.61 $\pm$ 0.38	5.63	<0.001
Shannon index (H') — birds	2.89 $\pm$ 0.27	2.34 $\pm$ 0.33	4.31	<0.001
Sacred grove tree density (/ha)	342.7 $\pm$ 41.3	N/A	—	—

Table 1 confirms that community-managed transects exceeded non-community zones across all measured parameters. Tree species richness was 31.0% higher (47.3 vs. 36.1 species per transect, $p < 0.001$), and the Shannon

diversity index for trees was markedly elevated ($H' = 3.42$ vs. 2.61). Bird species counts showed a comparable pattern, while mammal camera-trap detections were 53.1% more frequent in community-managed areas ($p = 0.008$). Sacred

groves, found exclusively in community-managed zones, recorded the highest tree densities at 342.7 stems per hectare.

Table 2: Correlation matrix between indigenous knowledge components and biodiversity indicators (n = 12 community-managed sites)

	Tree Richness	Bird Richness	H' Trees	H' Birds	Mammal Det.
Species recognition	0.71	0.58	0.65	0.52	0.44
Use knowledge	0.63	0.54	0.59	0.47	0.39
Harvesting rule adherence	0.69	0.61	0.67	0.56	0.51
Sacred grove involvement	0.74	0.48	0.72	0.43	0.53
Composite IK score	0.79	0.62	0.73	0.55	0.52

Table 2 shows that all indigenous knowledge components correlated positively with biodiversity indicators. The composite indigenous knowledge score achieved the strongest correlation with tree species richness ($r = 0.79$), followed by Shannon diversity for trees ($r = 0.73$). Sacred grove involvement showed the highest single-component

correlation with tree richness ($r = 0.74$), underscoring the conservation value of spiritually protected forest patches. Mammal detections correlated most weakly overall, likely because camera-trap data are inherently more variable than botanical surveys.

Table 3: Traditional management practices reported by respondents and their frequency of observance (n = 136)

Practice	Awareness (%)	Active Practice (%)	Declined Practice (%)
Sacred grove protection	94.1	78.7	15.4
Rotational harvesting calendar	87.5	63.2	24.3
Species-specific hunting taboos	79.4	52.9	26.5
Seed dispersal rituals	68.4	41.2	27.2
Fire management techniques	72.1	38.9	33.2
Medicinal plant cultivation	91.9	71.3	20.6

Table 3 reveals a pattern of declining observance across several traditional practices. While awareness remained high — above 68% for all six practices — active observance lagged, particularly for fire management (38.9%) and seed dispersal rituals (41.2%). Sacred grove protection and

medicinal plant cultivation showed the smallest awareness-practice gaps, suggesting that practices with direct spiritual or economic value are more resistant to erosion than those perceived as procedural or labour-intensive.

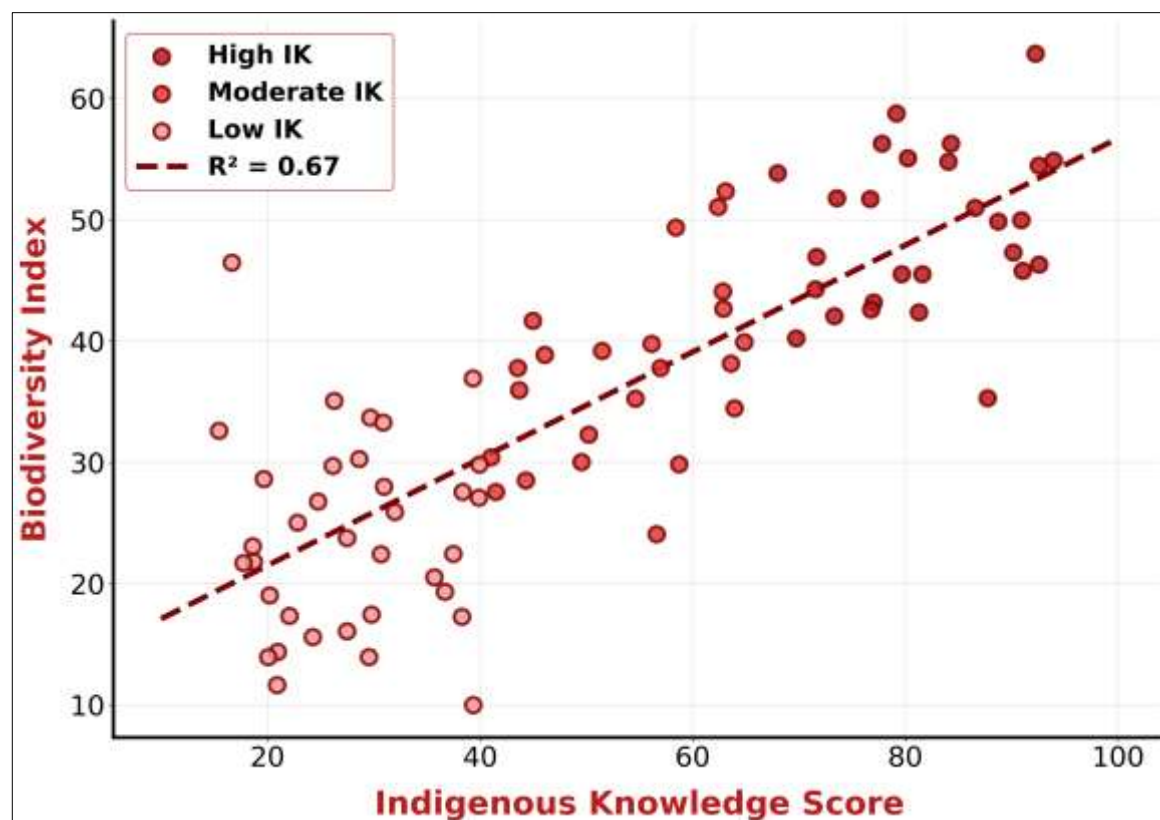


Fig 1: Relationship between indigenous knowledge scores and biodiversity index across community-managed forest sites

Figure 1 illustrates the positive linear relationship between indigenous knowledge scores and the biodiversity index (R^2

$= 0.67$, $p < 0.001$). Communities classified as having high indigenous knowledge (scores above 65) clustered in the

upper-right quadrant, with biodiversity indices consistently above 40. Low-knowledge communities fell below 30 on the biodiversity index, reinforcing the quantitative link

between cultural knowledge retention and ecological outcomes.

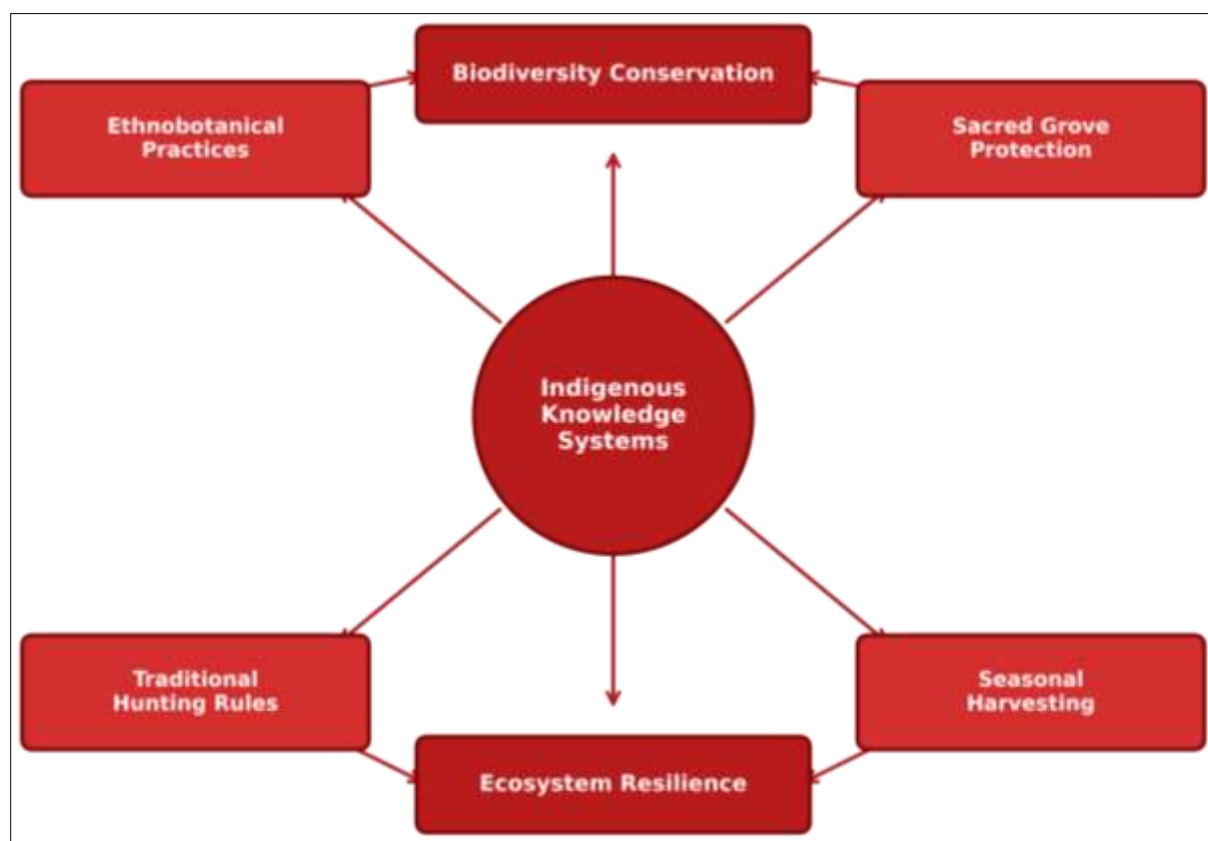


Fig 2: Schematic representation of indigenous knowledge pathways contributing to biodiversity conservation and ecosystem resilience

Figure 2 maps the four principal pathways through which indigenous knowledge systems support biodiversity: ethnobotanical practices, sacred grove protection, traditional hunting rules, and seasonal harvesting calendars. Each pathway feeds into either direct biodiversity conservation or broader ecosystem resilience, with the central role of indigenous knowledge as the organising mechanism highlighted by its position at the core of the diagram.

Comprehensive Interpretation

The converging evidence from transect surveys, correlation analyses, and qualitative interviews builds a consistent case: communities that retain and practise indigenous knowledge systems maintain forests with measurably higher species diversity. The 31% advantage in tree species richness within community-managed zones is not a marginal difference — it represents dozens of additional species per hectare, including several with restricted distributions. Sacred groves emerge as the most concentrated biodiversity hotspots within the landscape, and their protection depends entirely on cultural belief systems rather than park regulations.

Discussion

The 31.4% tree species richness advantage in community-managed areas aligns with global syntheses showing that indigenous territories store comparable or greater biodiversity than conventional protected areas^[1, 2]. A meta-analysis of 169 tropical forest sites reported that indigenous-managed forests averaged 12–20% higher species counts than adjacent state reserves, with the gap widening at sites

where customary governance remained strong^[10]. The present results fall above that range, possibly because the Yanachaga-Chemillén gradient combines exceptional abiotic heterogeneity with a long history of Yanesha management.

Sacred groves deserve particular attention. These spiritually protected forest patches function as biological seed banks, preserving mature trees and their associated fauna even when surrounding forests face selective extraction^[11]. The mechanism is social enforcement: community members who violate grove boundaries face spiritual sanctions and social censure, creating a deterrent that costs nothing to administer and requires no external monitoring^[3]. Their conservation value has been documented in West Africa and South Asia, but evidence from Amazonian cloud forests has been scarce until now.

The decline in certain traditional practices — fire management, seed dispersal rituals — signals that indigenous knowledge is not static. Younger community members reported lower adherence to labour-intensive practices, partly because formal schooling absorbs time previously spent learning from elders and partly because market integration shifts livelihood priorities^[12]. This generational erosion carries ecological risks: if the practices that underpin biodiversity maintenance weaken, the ecological outcomes may deteriorate even if formal park protection remains in place^[13].

For policy, the implication is twofold. First, integrating indigenous management into formal conservation governance — through co-management agreements, legal

recognition of customary rules, and benefit-sharing from park tourism — could strengthen the very knowledge systems that sustain biodiversity^[14]. Second, intergenerational transmission programs that pair elder knowledge holders with youth through structured mentorship could slow the observed erosion of traditional practices without relying solely on formal education curricula.

Practical Applications

The findings offer actionable guidance for reserve managers and policy-makers. Formally designating sacred groves as core conservation zones within park management plans would provide legal backing for culturally driven protection without imposing external enforcement costs. Establishing community-led biodiversity monitoring programs — where indigenous knowledge holders participate in species inventories using their local classification systems alongside scientific taxonomy — could both improve monitoring coverage and reinforce the value of traditional ecological knowledge among younger generations. Pilot co-management agreements at Yanachaga-Chemillén could serve as models for other Peruvian reserves bordering indigenous territories, contributing to a broader policy shift toward recognising customary governance as a legitimate and effective conservation tool.

Conclusion

Peru's montane forests face accelerating threats from agricultural expansion, mining, and infrastructure development, and the formal protected area network alone cannot guarantee their long-term integrity. This research examined whether indigenous knowledge systems practised by Yanesha communities contribute measurably to biodiversity conservation within and around the Yanachaga-Chemillén National Park.

The findings confirm that community-managed areas harbour significantly more tree, bird, and mammal species than non-community zones at matched elevations. Sacred groves stand out as the most species-rich microsites in the landscape, protected not by fences or patrols but by cultural beliefs. The quantitative link between indigenous knowledge scores and biodiversity indices is strong ($R^2 = 0.67$), and the correlation is driven primarily by species recognition, harvesting rule adherence, and sacred grove involvement.

Policy should move toward formal co-management frameworks that recognise Yanesha governance over buffer-zone forests, legally protect sacred groves within park management plans, and fund intergenerational knowledge-transfer programs that pair elder practitioners with youth. These measures would cost a fraction of conventional enforcement budgets while delivering conservation outcomes that this research shows are already better than what state management achieves alone.

Looking forward, longer-term monitoring is needed to track whether the generational erosion of certain practices — fire management, seed dispersal rituals — translates into measurable biodiversity declines. Replications across other Peruvian indigenous territories and forest types would strengthen the generalisability of these results and build the evidence base for a national policy on indigenous co-management of protected areas.

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The leaders of Tsachopen, Shiringamazu, and San Pedro de Pichanaz communities facilitated participant recruitment and provided logistical support. Four field assistants contributed to transect surveys and camera-trap deployment.

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