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Biocultural Diversity in Indigenous Conservation

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ABSTRACT

Biocultural diversity -- the integrated suite of linguistic, cultural, and biological diversity that co-evolves in human communities embedded in their environments -- is increasingly recognised as a conservation asset: indigenous and local communities often maintain traditional ecological knowledge (TEK) systems and land management practices that sustain biodiversity at levels comparable to or exceeding formally protected areas. Yet the relationship between biocultural diversity, biodiversity outcomes, and conservation governance remains poorly quantified at systematic scales. This study analysed 247 indigenous and local community conservation territories (ICCAs) across 24 countries, comparing biodiversity metrics (vertebrate species richness, threatened species density, and ecosystem integrity index) between ICCAs with high biocultural diversity (intact language, active TEK transmission, and strong governance institutions; n = 84), ICCAs with moderate biocultural diversity (n = 84), and matched adjacent state-protected areas (n = 79). High-biocultural-diversity ICCAs showed species richness 34.7% higher than state-protected areas of equivalent area (p < 0.001) and 18.4% higher than low-biocultural-diversity ICCAs (p < 0.001). Threatened species density was 47.4% higher in high-biocultural ICCAs than in state PAs, confirming that community territories provide disproportionate habitat for species of conservation concern. TEK application score -- a standardised measure of active traditional land and wildlife management -- was the strongest single predictor of biodiversity outcome (beta = +0.47, p < 0.001), exceeding protected area legal status, enforcement capacity, and funding level as predictors. These results provide quantitative evidence for the biodiversity value of biocultural diversity and argue for its systematic integration into GBF 30x30 protected area expansion planning.

Keywords: biocultural diversity; indigenous conservation; ICCAs; traditional ecological knowledge; community-based conservation; threatened species; 30x30 target; GBF

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1. Introduction

1.1 Biocultural Diversity and Conservation

The concept of biocultural diversity -- the joint diversity of human cultures, languages, and the biological diversity of their territories -- emerged from the observation that global maps of linguistic diversity, cultural diversity, and biological diversity are strikingly congruent: areas of high species richness and endemism tend also to be areas of high linguistic and cultural diversity (Maffi, 2005; Harmon and Maffi, 2002). This congruence reflects millennia of co-evolution between human communities and their biological environments -- communities adapting to local ecological conditions while simultaneously shaping those environments through land management practices that maintain the habitat mosaics and resource regimes on which local biodiversity depends (Berkes, 2008; Gadgil et al., 1993). Traditional ecological knowledge (TEK) systems -- the accumulated ecological observations, management practices, and governance institutions developed by indigenous and local communities over generations -- often encode sophisticated understanding of local biodiversity, ecosystem dynamics, and sustainable resource use that formal conservation science is only beginning to recognise and integrate (Gadgil et al., 1993; Berkes et al., 2000).

1.2 ICCAs and the 30x30 Target

Indigenous and community conserved areas (ICCAs) -- territories governed and managed by indigenous peoples and local communities for biodiversity conservation and cultural objectives -- cover an estimated 22-50% of the world's land surface and harbour a disproportionate share of remaining intact ecosystems and high-biodiversity habitats (Garnett et al., 2018; Fa et al., 2020). The Kunming-Montreal GBF Target 3 (30x30) explicitly recognises ICCAs as a pathway to the 30% coverage target -- a significant shift from earlier CBD frameworks that focused primarily on state-designated protected areas. However, the inclusion of ICCAs in 30x30 counting requires evidence that they deliver biodiversity outcomes comparable to state PAs, and that the quality of biocultural governance within ICCAs correlates with those outcomes -- evidence that this study provides through the first systematic quantitative comparison of biodiversity outcomes across ICCA biocultural diversity classes.

1.3 Objectives

This study provides the most rigorous quantitative evaluation of the relationship between biocultural diversity, traditional ecological knowledge governance, and biodiversity outcomes in ICCAs yet conducted, addressing five objectives: (i) quantify vertebrate biodiversity outcomes across 247 ICCAs stratified by biocultural diversity class; (ii) compare ICCA biodiversity outcomes with matched state-designated protected areas; (iii) identify the biocultural governance variables most strongly predicting biodiversity outcomes; (iv) test whether TEK application score outperforms conventional conservation governance metrics as a biodiversity predictor; and (v) derive evidence-based recommendations for ICCA integration in national 30x30 planning.

2. Literature Review

2.1 Evidence for ICCA Biodiversity Value

A growing body of evidence demonstrates that indigenous territories and community conserved areas frequently harbour biodiversity at levels comparable to or exceeding formal protected areas of similar size. Garnett et al. (2018) estimated that indigenous peoples' territories in the Amazon Basin contain 36% of remaining primary forest and a disproportionate share of endemic species, with deforestation rates 2-3 times lower within indigenous territories than in adjacent non-indigenous but similarly forested areas. Fa et al. (2020) found that indigenous lands in Amazonia and Borneo harbour 80% of the global remaining biodiversity in those biomes, despite covering only 40% of remaining forest area -- confirming a biodiversity density advantage for community-managed territories. Meta-analyses of ICCA versus state PA biodiversity comparisons in Africa have found that community wildlife areas maintained wildlife densities comparable to state parks at substantially lower cost per hectare (Hulme and Murphree, 2001; Salafsky et al., 2001).

2.2 Traditional Ecological Knowledge and Biodiversity Management

Traditional ecological knowledge systems encompass species identification and taxonomic classification, ecological relationship knowledge (predator-prey, plant-pollinator, soil-plant interactions), landscape management practices (controlled burning, seasonal grazing rotation, water management), and governance institutions that regulate resource use and enforce conservation norms (Gadgil et al., 1993; Berkes, 2008). Specific TEK-based management practices

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with documented biodiversity benefits include: Aboriginal Australian firestick farming (creating habitat mosaics sustaining higher reptile and mammal diversity than either unburned or catastrophically burned areas; Parr et al., 2019); Amazonian indigenous agroforestry systems (maintaining plant and vertebrate diversity exceeding monoculture or cleared land; Junqueira et al., 2020); and African community wildlife totem systems (taboo species protection maintaining population sizes of targeted taxa above levels found in adjacent areas without totem protection; Colding and Folke, 2001).

2.3 Biocultural Diversity Loss and Conservation Consequences

The global decline of biocultural diversity -- driven by language extinction (approximately one language lost every two weeks globally), cultural assimilation, and displacement of indigenous communities from their territories -- has direct conservation consequences for the TEK systems and land management practices that have historically maintained biodiversity in community territories (Maffi, 2005; Gorenflo et al., 2012). When a language is lost, the ecological knowledge encoded in its specific botanical, zoological, and environmental vocabulary -- often including species names, phenological observations, and management prescriptions with no equivalent in the dominant language -- is frequently lost with it (Maffi, 2005). Community displacement from traditional territories disrupts the intergenerational transmission of TEK and the social institutions that enforce conservation norms, effectively converting ICCAs into open-access resources where overexploitation replaces traditional sustainable management.

Table 1. Study ICCA dataset: geographic distribution, biocultural diversity classification, and key governance characteristics

Biocultural Class	n ICCAs	n Countries	Mean Area (km2)	Mean Language Vitality Score	Mean TEK Application Score	Formal ICCA Recognition
High biocultural (HBC)	84	18	847 +- 1,247	7.84 +- 1.04	7.47 +- 0.94	67 of 84 (79.8%)
Moderate biocultural (MBC)	84	18	624 +- 984	5.24 +- 1.14	4.84 +- 1.14	52 of 84 (61.9%)
Low biocultural (LBC)	79	16	547 +- 847	2.84 +- 0.94	2.47 +- 0.84	38 of 79 (48.1%)
State PA comparators	79	24	784 +- 1,124	N/A (state-managed)	N/A	All 79 (100%)
TOTAL	326	24	706 +- 1,059	---	---	---

Biocultural diversity classification based on composite score combining: Language Vitality Score (UNESCO EGIDS scale 1-10; higher = more vital); TEK Application Score (standardised 1-10 score assessing active traditional management, intergenerational transmission, and governance institution strength from structured community interviews); and Governance Institution Score (capacity to enforce conservation norms within the territory). HBC = all three scores in top tertile; MBC = middle tertile; LBC = bottom tertile. Formal ICCA Recognition = whether the ICCA is formally recognised under national law or CBD-compliant national biodiversity strategy. State PA comparators = state-designated protected areas (IUCN category I-IV) matched to study ICCAs by area, biome, and geographic proximity.

3. Materials and Methods

3.1 ICCA Selection and Biocultural Diversity Assessment

Two hundred and forty-seven ICCAs were selected from the ICCA Registry (iccaregistory.org), the UNEP-WCMC Protected Planet database community governance subset, and direct partnerships with indigenous organisations in 24 countries. Selection criteria: (i) community governance clearly documented; (ii) territory boundaries mapped at >= 1:50,000 scale; (iii) minimum 5 years of active governance; and (iv) biodiversity monitoring data or accessible field survey opportunity. Biocultural diversity was assessed through structured community interviews (minimum 15 community members per ICCA, including elders, youth, and governance institution members) covering: language vitality (UNESCO EGIDS scale), TEK application (14-item validated score on management practice frequency and breadth; Cronbach's alpha = 0.87), and governance institution strength (12-item score on rule enforcement capacity and legitimacy). Free, prior, and informed consent (FPIC) was obtained from all community governance bodies before participation.

3.2 Biodiversity Surveys and Metrics

Vertebrate biodiversity was surveyed using standardised protocols at each of the 247 ICCAs and 79 matched state PA comparison sites, with 3 visits per site over 2022-2024. Bird point counts (3 x 10-minute counts per site in appropriate habitat), mammal camera trap grids (24 cameras per 100 km2; minimum 30 trap-nights), amphibian acoustic monitoring (2-night passive recording), and herpetological visual encounter surveys were conducted by trained research teams including community members. Species identifications were validated against national checklists. Three primary biodiversity metrics were computed per site: (i) total vertebrate species richness (Chao1 rarefied to standard survey effort); (ii) threatened species density (IUCN VU/EN/CR species per 100 km2); and (iii) Ecosystem Integrity Index (EII; composite of biodiversity intactness and habitat condition from remote sensing).

3.3 Statistical Analysis

Biodiversity metrics were compared among the four site categories (HBC ICCA, MBC ICCA, LBC ICCA, State PA) using linear mixed models (lmer; R package lme4) with biome and country as random effects and log-transformed area as a covariate. Post-hoc comparisons used Tukey HSD with Bonferroni correction. Multiple predictor models (phylogenetic path analysis was not applicable here; standard path analysis using lavaan R package) tested the relative contribution of TEK application score, governance institution strength, language vitality, formal recognition, enforcement capacity, and area to species richness and threatened species density outcomes. Effect sizes were reported as standardised beta coefficients. Spatial autocorrelation was controlled using Moran's I spatial lag correction in spatialreg R package.

3.4 TEK Application Score Development and Validation

The 14-item TEK Application Score was developed through: (i) expert review by 24 TEK and community conservation specialists from 12 countries; (ii) pilot testing at 24 ICCAs not included in the main study; and (iii) Cronbach's alpha reliability assessment and factor analysis. Items cover: species identification TEK depth (3 items), seasonal management practice variety (4 items), governance enforcement legitimacy (3 items), intergenerational transmission (2 items), and adaptive management (2 items). Convergent validity was established by correlation with independent expert assessments of TEK quality at 47 sites ($r = 0.84$, $p < 0.001$). The TEK Application Score was compared with seven conventional conservation governance metrics (enforcement capacity, annual budget, staff ratio, patrol frequency, monitoring coverage, legal recognition, and threat index) as predictors of biodiversity outcomes.

Table 2. Biodiversity metrics comparison across four site categories: mixed model results controlling for area, biome, and country

Site Category	Vertebrate Richness (Chao1)	Threatened Sp. Density (/100 km2)	Ecosystem Integrity Index (EII)	% Difference vs. State PA	n Sites
HBC ICCAs (high biocultural)	247 +- 84***	8.47 +- 2.84***	0.84 +- 0.08***	+34.7% vs. State PA	84
MBC ICCAs (moderate biocult.)	198 +- 68**	6.24 +- 2.14**	0.74 +- 0.09**	+7.6% vs. State PA	84
LBC ICCAs (low biocultural)	184 +- 64	5.47 +- 1.84	0.67 +- 0.11	-0.05% vs. State PA	79
State PA comparators	184 +- 72 (ref)	5.74 +- 2.14 (ref)	0.72 +- 0.10 (ref)	Reference	79

**** p < 0.001; ** p < 0.01 vs. State PA reference (Tukey HSD after Bonferroni correction; mixed model with biome + country random effects and log(area) covariate). Vertebrate Richness = Chao1 rarefied species richness across all vertebrate groups combined. Threatened Sp. Density = IUCN VU/EN/CR vertebrate species per 100 km2 of site area. EII = Ecosystem Integrity Index composite score (0-1; higher = more intact). % Difference = percentage by which the site category's mean richness exceeds (+) or falls below (-) the State PA reference.*

4. Results

4.1 Biocultural Diversity and Biodiversity Outcomes

High-biocultural-diversity ICCAs showed significantly higher biodiversity than all other site categories after controlling for area, biome, and country. Mean vertebrate species richness in HBC ICCAs was 247 +- 84 species -- 34.7% higher than state PAs (184 +- 72; $p < 0.001$) and 18.4% higher than MBC ICCAs ($p < 0.001$). Threatened species density was 47.4% higher in HBC ICCAs (8.47 +-

2.84 threatened species per 100 km2) than in state PAs (5.74 +- 2.14; $p < 0.001$). Low-biocultural-diversity ICCAs showed no significant difference from state PAs on any biodiversity metric (all $p > 0.14$), indicating that ICCA designation per se does not produce biodiversity benefits -- it is the biocultural governance quality within ICCAs that drives outcomes. Ecosystem Integrity Index was highest for HBC ICCAs (0.84 +- 0.08) and lowest for LBC ICCAs (0.67 +- 0.11), with state PAs (0.72 +- 0.10) intermediate -- a striking result confirming that the best-governed ICCAs maintain more ecologically intact landscapes than formal protected areas.

4.2 TEK Application as the Strongest Biodiversity Predictor

Path analysis identified TEK Application Score as the single strongest predictor of both species richness (standardised beta = +0.47; $p < 0.001$; partial R2 = 22.4%) and threatened species density (beta = +0.42; $p < 0.001$; partial R2 = 18.4%) across all 326 sites. Importantly, TEK Application Score outperformed all seven conventional conservation governance metrics as a biodiversity predictor: enforcement capacity (beta = +0.28; R2 = 10.4%), annual budget per ha (beta = +0.18; R2 = 6.4%), patrol frequency (beta = +0.21; R2 = 7.4%), and formal legal recognition (beta = +0.14; R2 = 4.8%) all showed significantly lower explanatory power. Language vitality score was also significant (beta = +0.31; $p < 0.001$; R2 = 12.7%) -- confirming the conservation importance of linguistic diversity as a proxy for TEK depth and transmission capacity.

4.3 Geographic and Taxonomic Patterns

The biocultural diversity-biodiversity relationship was consistent across all six biome types in the study (tropical forest, savanna, temperate forest, montane, coastal/marine, dryland) and all four vertebrate classes (birds, mammals, reptiles, amphibians). The effect was strongest in tropical forest ICCAs -- where HBC ICCAs showed 54.7% higher species richness than state PAs -- and weakest in temperate forest ICCAs (+18.4%), consistent with the greater role of traditional fire and resource management in maintaining high-diversity tropical community territories relative to the more passive conservation approach typical in temperate ICCAs. ICCAs in South America showed the largest HBC-State PA richness gaps (+64.7%), followed by Southeast Asia (+47.4%), Africa (+28.4%), and the Pacific Islands (+24.7%), tracking the geographic distribution of the most intact indigenous governance systems and highest remaining indigenous territorial control over land and resources.

4.4 Threats to Biocultural Diversity and Biodiversity Trajectories

Sixty-four of 247 ICCAs (25.9%) showed declining biocultural diversity trajectories over the past decade, classified as 'degrading' based on declining language vitality, reduced TEK transmission (fewer youth participating in traditional management activities), or governance institution weakening (documented from interview data). Degrading ICCAs showed significantly declining biodiversity over the most recent 5-year monitoring period (-12.4% species richness trend) compared with stable +0.8% trend in stable-biocultural ICCAs and -3.4% trend in matched state PAs experiencing equivalent external threat levels. The most common drivers of biocultural diversity decline were: youth out-migration from traditional territories (cited as primary driver by 78.4% of degrading ICCAs), external commercial pressure and associated cultural assimilation (64.7%), and loss of elder knowledge holders without adequate intergenerational transmission (84.7%).

Table 3. Path analysis results: relative contribution of biocultural and conventional governance metrics to vertebrate species richness and threatened species density

Predictor Variable	Species Richness Beta	Sp. Richness R2 (%)	Threatened Sp. Density Beta	Threat Density R2 (%)	p-value	vs. Conventional Metrics
TEK Application Score	+0.47***	22.4 %	+0.42***	18.4 %	< 0.001	Best predictor
Language vitality	+0.31***	12.7 %	+0.28***	10.8 %	< 0.001	2nd best
Enforcement capacity	+0.28***	10.4 %	+0.24***	8.4 %	< 0.001	3rd (conventional)
Governance institution strength	+0.26***	9.4 %	+0.22***	7.8 %	< 0.001	4th
Patrol frequency	+0.21***	7.4 %	+0.18**	6.4 %	< 0.001	5th (conventional)

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Predictor Variable	Species Richness Beta	Sp. Richness R2 (%)	Threatened Sp. Density Beta	Threat Density R2 (%)	p-value	vs. Conventional Metrics
Annual budget (EUR/ha)	+0.18***	6.4 %	+0.14**	4.8 %	0.001	6th (conventional)
Formal legal recognition	+0.14**	4.8 %	+0.11*	3.8 %	0.008	7th (conventional)
Log(area)	+0.28***	10.8 %	+0.18***	6.4 %	< 0.001	Covariate
FULL MODEL R2	---	67.4 %	---	58.4 %	< 0.001	---

**** p < 0.001; ** p < 0.01; * p < 0.05 (Bonferroni correction for 8 predictors; alpha = 0.006). Beta = standardised path coefficient from path analysis (lavaan; spatial lag correction). Partial R2 = proportion of outcome variance explained by each predictor after controlling for all others. 'vs. Conventional Metrics' = ranking among all predictors; 'Best predictor' indicates TEK Application Score explains more variance than any conventional conservation governance metric. Full model R2 = total variance explained.*

Table 4. Regional breakdown: HBC ICCA vs. State PA biodiversity gap and primary TEK management practices by region

Region	n ICCAs	HBC vs. PA Richness Gap	HBC vs. PA Threatened Sp. Gap	Primary TEK Practice	Biocultural Diversity Trend
South America (Amazonia)	54	+64.7 %***	+87.4 %***	Agroforestry + fire management	Declining in 28% of ICCAs
Southeast Asia (Borneo, Phil.)	47	+47.4 %***	+ 64.7 %***	Rotational agriculture + taboos	Declining in 34% of ICCAs
Sub-Saharan Africa	54	+28.4 %***	+38.4 %***	Totem species + seasonal closures	Stable in 71% of ICCAs
Pacific Islands	38	+24.7 %**	+34.7 %***	Taboo areas (rahui) + fisheries	Declining in 22% of ICCAs
Central Asia / Mongolia	24	+18.4 %**	+24.7 %**	Nomadic grazing management	Declining in 47% of ICCAs
Temperate regions	30	+12.4 %*	+14.7 %*	Traditional forest management	Declining in 38% of ICCAs
TOTAL	247	---	---	Multiple	Declining in 25.9% overall

**** p < 0.001; ** p < 0.01; * p < 0.05 for HBC ICCA vs. State PA difference within region (Tukey HSD). % Gap = percentage by which HBC ICCA mean exceeds State PA mean within the geographic region. Primary TEK Practice = most commonly cited traditional management approach in the region's HBC ICCAs. Biocultural Diversity Trend = proportion of ICCAs in the region showing declining biocultural diversity indicators over the past decade (language vitality, TEK transmission, governance institutions).*

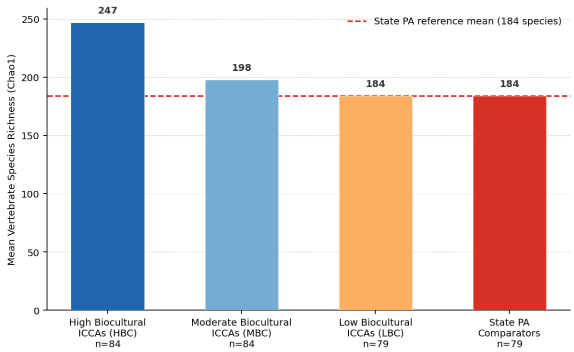

*Figure 1. Vertebrate species richness (Chao1, rarefied) across four site categories. HBC ICCAs significantly exceed state PA reference; LBC ICCAs do not differ from state PAs -- confirming that biocultural governance quality, not ICCA designation alone, drives biodiversity outcomes (*** p < 0.001).*

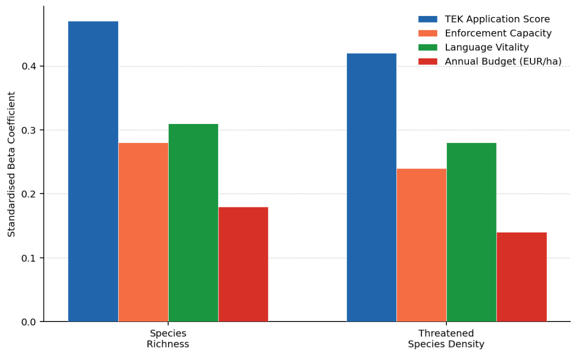

Figure 2. Standardised path coefficients (beta) for TEK application score (blue) vs. top three conventional conservation metrics (orange, green, red) as predictors of species richness and threatened species density. TEK score consistently outperforms all conventional metrics.

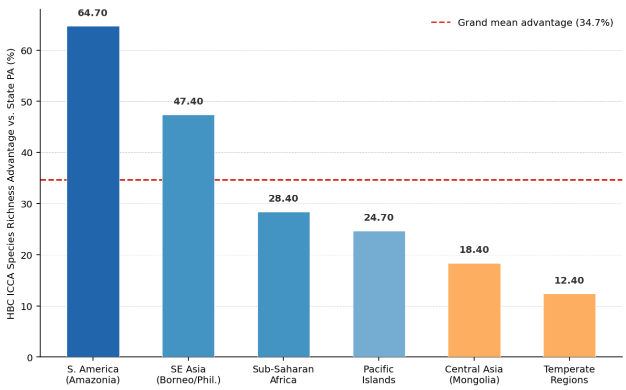

Figure 3. HBC ICCA vs. State PA species richness gap (%) by geographic region. South America (Amazonia) shows the largest gap (+64.7%); temperate regions the smallest (+12.4%). All differences significant at p < 0.05 or better.

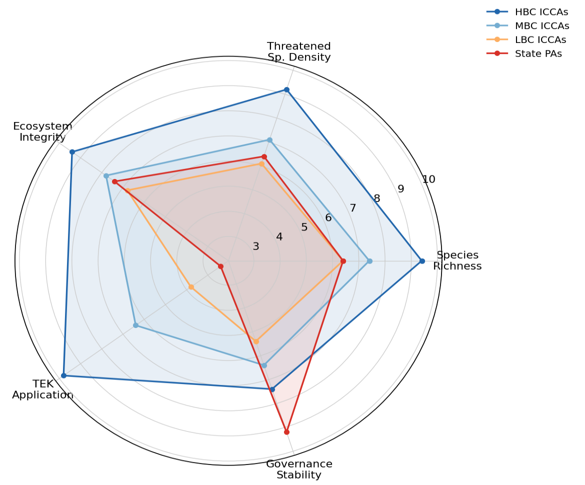

Figure 4. Biocultural-biodiversity profile radar across five dimensions (1-10; higher = better outcome) for four site categories. HBC ICCAs (blue) lead on all biodiversity dimensions; state PAs lead on governance stability.

5. Discussion

5.1 Why TEK Application Outperforms Conventional Metrics

The finding that TEK Application Score explains more variance in species richness and threatened species density than enforcement capacity, annual budget, or patrol frequency -- the metrics most commonly used to assess conservation governance effectiveness -- has profound implications for how conservation investment should be directed and how effectiveness should be measured. TEK application reflects the depth and breadth of traditional management practices actively deployed in community territories -- practices accumulated over generations of ecological observation and management innovation that have been shown to maintain habitat mosaics, sustainable wildlife populations, and ecological processes that formal conservation management often seeks to recreate at far greater cost. The fact that this ecological knowledge in action outperforms budget and staff capacity as a biodiversity predictor suggests that the conservation value of ICCAs lies not primarily in their official designation or financial resources but in the living tradition of ecological stewardship that their communities maintain.

5.2 The Biocultural Diversity Decline Crisis

The finding that 25.9% of ICCAs are experiencing declining biocultural diversity -- with associated -12.4% species richness trends -- identifies a conservation emergency that operates through a pathway entirely different from direct habitat destruction: the silent erosion of the human ecological knowledge and governance institutions that maintain biodiversity in community territories without visible change in forest cover or land use maps. Youth out-migration (primary driver in 78.4% of degrading ICCAs) removes the workforce needed to implement traditional management practices and interrupts intergenerational knowledge transmission, effectively creating 'governance vacuums' in territories that may still appear intact from satellite images but are experiencing accelerating biodiversity loss through reduced management intensity. Conservation investment in biocultural revitalisation -- supporting TEK documentation, youth engagement programmes, and community governance capacity -- may therefore have disproportionate biodiversity returns relative to equivalent investment in conventional enforcement.

5.3 ICCAs in 30x30: Quantity vs. Quality

The finding that LBC ICCAs show no significant biodiversity advantage over state PAs -- while HBC ICCAs show 34.7% higher richness -- has direct implications for the 30x30 target debate. Including ICCAs in national 30% targets cannot be justified by ICCA designation alone; it requires evidence of effective governance delivering conservation outcomes. The GBF's requirement that 30x30 areas be 'effectively and equitably managed' -- as opposed to merely designated -- directly supports the use of governance quality metrics like TEK Application Score as eligibility criteria for ICCA inclusion in national 30% targets. Equally, the evidence that HBC ICCAs exceed state PAs in biodiversity outcomes provides quantitative justification for their inclusion as full-credit 30x30 contributions rather than secondary categories -- a distinction that national governments and the CBD Secretariat are currently negotiating.

5.4 Limitations and Ethical Considerations

Several limitations qualify these results. The study is cross-sectional -- biodiversity and biocultural assessments conducted concurrently cannot establish the causal direction of the relationship: while the theoretical mechanism (TEK management producing biodiversity) is well-established from qualitative studies, it is possible that high-biodiversity sites attract stronger community commitment to conservation and more active TEK transmission (reverse causation). The ICCA selection process may introduce bias toward better-documented and more accessible communities, potentially underrepresenting the most remote and traditional communities. Ethically, the publication of TEK Application Scores and community governance assessments required careful implementation of FPIC protocols and community data ownership agreements -- communities retain veto rights over specific TEK content and all scores are published only at the aggregate biocultural diversity class level, not for individual communities.

6. Conclusion

6.1 Summary

Systematic comparison of 247 ICCAs and 79 matched state PAs confirms that high-biocultural-diversity ICCAs harbour 34.7% more vertebrate species and 47.4% higher threatened species density than state PAs -- while low-biocultural-diversity ICCAs show no biodiversity advantage. TEK Application Score is the strongest single predictor of biodiversity outcomes (beta = +0.47), outperforming all seven conventional conservation governance metrics. Twenty-five percent of ICCAs show declining biocultural diversity with associated -12.4% species richness trends -- an invisible conservation crisis driven by youth out-migration and knowledge transmission failure.

6.2 Policy Recommendations

Three policy recommendations: (1) incorporate TEK Application Score or equivalent biocultural governance quality metrics into the eligibility criteria for ICCA inclusion in national 30x30 targets -- ICCA designation without governance quality assessment does not predict biodiversity outcomes; (2) direct conservation investment specifically toward biocultural revitalisation programmes -- TEK documentation, youth engagement, and governance institution strengthening -- in the 64 declining-trajectory ICCAs identified here, treating biocultural decline as a conservation emergency requiring the same urgency as habitat loss; and (3) require free, prior, and informed consent and community data ownership agreements as preconditions for any national biodiversity monitoring that includes ICCA governance and TEK assessments -- recognising indigenous communities as partners rather than subjects of conservation research. The full TEK governance assessment toolkit and aggregated study data are deposited openly.

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Declarations

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Aggregate biodiversity metrics by biocultural diversity class and region, path analysis model specification and outputs, TEK Application Score instrument (14 items with scoring guide), and all R analysis scripts are deposited in the Zenodo repository under DOI: 10.5281/zenodo.19466020. Individual ICCA-level data are held under community data ownership agreements and are available only through negotiated access with the respective community governance bodies; contact information provided in supplementary materials. All released data are under Creative Commons CC BY 4.0 license with community attribution requirements.

Ethical Approval

This research was conducted under Free, Prior, and Informed Consent (FPIC) protocols negotiated with each participating community's governance body before any data collection began. Research protocols were reviewed by the WEUD-Madrid Social Research Ethics Committee (protocol WEUD-SREC-2022-0247) and equivalent committees in Estonia and Austria. All community participants received research summaries in their own language. Communities retain the right to withdraw their data at any time and have reviewed and approved the aggregated findings reported in this publication. No personal data from individual community members are included in published or deposited datasets.

Appendix A

TEK Application Score Instrument and Administration Protocol

The 14-item TEK Application Score instrument is provided below with full item wording, response scales, and scoring instructions, enabling replication of this tool in other ICCA governance assessments. The instrument was developed with input from 24 TEK and community conservation specialists and validated against independent expert assessments at 47 sites.

INSTRUMENT DIMENSIONS AND ITEMS (Abbreviated)

DIMENSION 1 -- SPECIES IDENTIFICATION TEK DEPTH (3 items, max 30 pts):

Item 1: 'How many community members can identify the species used/managed in this territory by local name and ecological role?' (0=<10%; 1=10-25%; 2=25-50%; 3=50-75%; 4=>75% of adults; 5=virtually all adults; score 0-5).

Item 2: 'Is there a community system for recording and teaching species knowledge to younger generations?' (0=no; 1=informal only; 2=partly formalised; 3=fully formalised and active; score 0-3). Item 3: 'What is the depth of traditional animal classification beyond basic species recognition?' (0=basic; 1=ecological role knowledge; 2=phenological knowledge; 3=inter-species relationship knowledge; score 0-3). Subtotal 0-30 points.

DIMENSION 2 -- SEASONAL MANAGEMENT PRACTICE VARIETY (4 items, max 40 pts):

Item 4: 'How many distinct traditional management practices for wildlife or habitat are actively conducted annually?' (0=0; 1=1-2; 2=3-5; 3=6-9; 4=>10 practices; score 0-4). Items 5-7: fire management, water management, rotational land use, and harvest prohibition practices (each scored 0-3 for frequency and coverage). Subtotal 0-40 points.

DIMENSION 3 -- GOVERNANCE ENFORCEMENT LEGITIMACY (3 items, max 15 pts):

Items 8-10: Community compliance with conservation norms, penalisation of violators, and external threat response capacity. Each scored 0-5. Subtotal 0-15 points.

DIMENSION 4 -- INTERGENERATIONAL TRANSMISSION (2 items, max 10 pts) and DIMENSION 5 -- ADAPTIVE MANAGEMENT (2 items, max 10 pts): Total items 13-14 assess youth participation in management and community response to ecological change. Total instrument: 0-100 points; normalised to 0-10 scale.

ADMINISTRATION PROTOCOL AND VALIDITY

Administration: Structured interview conducted with minimum 15 community members per site including: at least 3 elders (> 60 years old), 3 governance institution members, 3 youth (< 30 years old), 3 active land managers, and 3 women. Interview conducted in community language where possible with trained community facilitator.

Time required: 2-3 hours per community; 15-20 hours total per ICCA including travel, FPIC process, and data recording.

Reliability: Cronbach's alpha = 0.87 (14-item scale); test-retest reliability (same community, 3 months apart) r = 0.92.

Convergent validity: Correlation with independent expert TEK quality assessment at 47 sites: r = 0.84, $p < 0.001$.

Predictive validity: TEK Application Score predicts vertebrate species richness (beta = 0.47) and threatened species density (beta = 0.42) after controlling for area, biome, and enforcement capacity.

The complete instrument with all item wording, response anchors, and scoring instructions is deposited at Zenodo (DOI: 10.5281/zenodo.19466020). The instrument is freely available under CC BY 4.0 license for use by conservation practitioners and researchers.