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Socio-Ecological Barriers to the Sustainable Management of the Andean Walnut (*Juglans neotropica*) and the Value Paradox in the Ecuadorian Andes

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Abstract

The Andean walnut (*Juglans neotropica* Diels), locally known as tocte, is a keystone tree species of major socio-ecological importance in South American mountain ecosystems; it faces severe anthropogenic pressure associated with genetic erosion, habitat fragmentation, and unregulated selective logging. This article applies a qualitative phenomenological approach to examine the power relations and institutional failures shaping the sustainable practice of its value chain in Imbabura Province, Ecuador. Drawing on 21 in-depth semi-structured conversations with key actors, including woodcarvers, sawyers, traders, authorities, and on thematic analysis supported by ATLAS.ti, we identified five thematic categories that reveal the tension between cultural valuation and market pressure. The findings confirm the existence of a value paradox: high demand for walnut timber in the artisanal center of San Antonio de Ibarra encourages premature harvesting of young trees, undermining the viability of non-timber forest products such as nuts, and accelerating the loss of local genetic resources. Interviewees consistently described bureaucratic barriers, informal commercialization, and weak collective organization as central obstacles to long-term viability; we conclude that the long-term conservation of the species requires a transition toward polycentric stewardship, community forestry enterprises, and integrated landscape management. These strategies should combine local knowledge with modern silvicultural practices, strengthen traceability and promote productive landscapes in which the standing tree is valued as much as the harvested timber.

Keywords: conservation of *Juglans neotropica*; forest management structures; non-timber forest product; sustainable value chain; Tropical Andes; adaptive management

1. Introduction

1.1. The Crisis of Forest Management in the Tropical Andes

Achieving long-term forest management in the Tropical Andes remains one of the most pressing obstacles for biodiversity conservation; this region is a global hotspot in which the socioeconomic needs of rural communities coexist with highly fragile mountain ecosystems [1–3]. The rapid expansion of agricultural frontiers, coupled with extensive logging and lack of sturdy spatial planning, has led to severe habitat fragmentation across multiple elevational gradients [4,5]. Within this context, non-timber forest product (NTFP) value chains have often been presented as mechanisms capable of reducing deforestation by assigning financial value to standing forests [6–8]. In principle, products such as fruits, resins, and ecosystem services can help create sustainable productive landscapes that align conservation goals with rural livelihoods and maintain historical cultural practices [9–11].

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Recent empirical evidence indicates that NTFP commercialization alone is insufficient when institutional oversight is weak, property rights are unclear and timber markets offer faster and more profitable returns [4,12,13]. Under such conditions, extraction tends to prevail over conservation, trapping communities in cycles of resource depletion [14,15]. This degradation affects not only high-value timber species but also specialized taxonomic groups, such as ferns and lycophytes, which are increasingly threatened by habitat loss in the western Andes [16,17]. The lack of coordination between environmental protection policies and productive agricultural mandates further exacerbates these crises, necessitating an approach that incorporates polycentric governance and enhanced social participation [18,19].

1.2. Juglans neotropica: A Species at a Crossroads

Juglans neotropica Diels, commonly known as the Andean walnut or tocte, is a flagship tree of cloud forests in Colombia, Ecuador, Peru, and Venezuela [20,21]. Beyond its botanical relevance, the species plays essential ecological roles, including hydrological regulation, soil stabilization, and habitat provision for associated biodiversity [1,22,23]. The species also exhibits a problematic financial duality. Its timber is highly valued for fine cabinetry and sculpture because of its distinctive color, durability, and workability, which drives intense demand in regional artisanal production centers [20,23]. At the same time, its nuts and derived products sustain a long-standing non-timber economy embedded in Andean culture, including culinary uses and traditional dyeing techniques [9,10,24].

Despite this broad value, *Juglans neotropica* is currently listed as Endangered on the IUCN Red List, facing critical threats from habitat clearance and overexploitation [17,20,21]. Conservation in biological hotspots like the Tropical Andes is a global imperative facing combined pressures from demographic growth, agricultural expansion, and high deforestation rates [1,4,5,23]. Systematic assessments confirm that even selective extraction of high-value timber drastically alters canopy structure and biodiversity, compromising regeneration [20,25,26]. Formalizing community forest management and empowering local rule-making are proven mechanisms for aligning conservation with local subsistence [18,27,28]. For restoration programs to be successful and resilient to climate change, it is fundamental to incorporate genetic diversity and accurately identify the provenances of native tree species before existing populations are entirely depleted [29–31]. Biophysical barriers to Andean forest restoration can be mitigated by excluding cattle grazing, which meaningfully enhances tree productivity and survival [32]. Understanding phenotypic variability and genetic vulnerability is a prerequisite for developing sustainable harvesting protocols that do not deplete wild populations [30,31,33]. Additionally, the complex reproductive biology of this monoecious species requires a high degree of landscape connectivity, which is being lost to the fragmentation of the Andean corridor [34,35].

1.3. The Value Paradox as a Theoretical Framework

Most recent studies on *Juglans neotropica* have focused on technical or biological dimensions, including genetic diversity, phenotypic variability under climate change, and agroforestry potential [20,30,36,37]. By contrast, relatively little attention has been paid to the sociopolitical conditions governing how the species is used, traded and consequently, conserved; the present research is framed through the concept of the value paradox proposed by Cronkleton et al. [13]. According to this perspective, a resource's high market value does not necessarily encourage protection; under weak management structures, it may instead accelerate depletion when immediate financial returns outweigh long-term management incentives [13]. In Ecuador, these dynamics are compounded where institutional failure, burdensome procedures for legal harvesting, and the strong presence of informal timber markets offer faster and more profitable returns [14,38].

To achieve true multifunctionality, the selective harvesting of *J. neotropica* must be actively managed alongside other forest products to prevent resource conflicts and maximize local community benefits [3,8,20]. The recent transition toward sustainability in Ecuadorian agricultural

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hubs provides a viable market-access blueprint for formalizing and certifying the Andean walnut timber trade and ensuring that local smallholders capture more of the generated value [14,39,40]. To navigate the complex market dynamics of high-value Andean products, collective action and multi-stakeholder platforms are essential for building trust and enabling smallholders to capture fair market value while minimizing reliance on exploitative intermediaries [28,41]. Protected areas in the Ecuadorian Andes must prioritize the conservation of *J. neotropica* as a keystone species for maintaining regional biodiversity [17]. The financial viability of managing slow-growing, high-value timber like *J. neotropica* can be more accurately assessed using Real Options Analysis (ROA) [42], which accounts for long-term price volatility and management flexibility. The value paradox is intensified by highly informal domestic timber markets in Ecuador, where intermediaries capture much of the profit while rural communities remain dependent on unregulated logging for basic cash income, often selling timber at prices that do not reflect its true ecological or artisanal worth [14,43]. This discrepancy between true value and market price structurally disincentivizes conservation and promotes rapid, unsustainable liquidation of standing tree assets [7,44].

1.4. Research Gap and Objectives

To address this gap, the present study offers an in-depth qualitative analysis of local perspectives in Imbabura, with particular emphasis on San Antonio de Ibarra, Ecuador's best-known artisanal woodcarving center [5,45]. While biological studies highlight the species' genetic vulnerability [31], there is a pressing need to understand how the actors along the commercial chain rationalize their resource use under conditions of scarcity [46,47]. The guiding research question is as follows: *Which institutional, financial, and cultural drivers shape local decision-making regarding the use and conservation of Juglans neotropica ?*

We hypothesize that a fragmented value chain, combined with weak collective action, favors short-term extractive strategies that marginalize sustainable silviculture and the potential of non-timber products. Accordingly, the objectives of this article are to:

(i) analyze the current configuration of the value chain as well as the power relations among actors [11,48]; (ii) identify the main sustainable practice bottlenecks perceived by stakeholders, particularly the tension between legality and economic necessity [13,14]; and (iii) propose intervention strategies grounded in participatory stewardship, community enterprises, and integrated landscape management [28,39,49].

2. Materials and Methods

2.1. Study Area

The study was conducted in Imbabura Province (0 deg 21′ N, 78 deg 08′ W) located in the northern Ecuadorian highlands (Figure 1). Recognized as a UNESCO Global Geopark in 2019, the province contains a highly diverse landscape in which remnants of montane cloud forest coexist with intensive agricultural land use and growing urban centers [5,45]. Recent multi-criteria assessments have identified areas suitable for the expansion of protected agriculture, highlighting persistent and intensifying tensions between agricultural production and environmental conservation [5,19]. San Antonio de Ibarra, a rural parish within this province, is particularly relevant to our study because of its long-standing and internationally recognized woodcarving tradition. Its role as a vital demand center for *Juglans neotropica* timber has historically led to significant extractive pressure on local and regional tree populations [1,20].

Advanced spatial methodologies, such as cloud-based remote sensing, are critical for accurately monitoring land-use changes and the ongoing degradation of remaining *J. neotropica* habitats across the province [12,45]. Similar to the commercialization of other non-timber forest products in the Amazon and Andes, the sustainable extraction of the Andean walnut requires targeted development interventions that match local household economic strategies and ensure secure resource tenure for rural farmers [8,50]. Formalizing the timber trade and implementing certification schemes can help

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ensure that the economic benefits of *J. neotropica* reach the actual land managers, thereby creating a financial justification for keeping the trees standing [14,43]. Intermediaries in the timber value chain often capture a disproportionate share of the profits, leaving local communities with minimal incentives to maintain standing forests, a phenomenon deeply embedded in regional informal economies [14,44]. The economic valuation of the full range of ecosystem services provided by the Andean walnut (including carbon sequestration, soil retention and cultural heritage support) is a necessary step for developing future Payment for Ecosystem Services (PES) schemes in Imbabura [1,22,44]. Equally important, comprehensive spatial analysis and remote sensing remain critical tools for identifying current *J. neotropica* distributions and prioritizing specific micro-watersheds for large-scale ecological restoration initiatives [12,45,51].

Figure 1. Study area in Imbabura Province.

2.2. Research Design

A qualitative phenomenological design was adopted to capture the lived experiences, perceptions, and social structures underlying natural resource management in this region [46,47]. This interpretative approach is especially suitable and methodologically sturdy for studying informal value chains where official quantitative statistics are limited, unreliable, or absent [14]. Phenomenology allows researchers to uncover how actors meaning-make around scarcity, legality, and economic survival, prioritizing the subjective realities of those directly interacting with the resource ecosystem [47].

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2.3. Participant Selection and Data Collection

Participants were purposively selected through non-probabilistic snowball sampling, a standard technique for accessing hard-to-reach populations embedded within informal commercial networks [46]. The process began with structured discussions with key informants, such as artisanal guild leaders and regional forestry professionals (e.g., MAATE technicians) and expanded systematically toward more dispersed and informal actors, including independent sawyers, nut collectors, transporters, and sculptors [14].

A total of 21 in-depth semi-structured interviews were conducted between March 2024 and September 2025 (Appendix B). The sample size was defined rigorously through the criterion of theoretical saturation, meaning fieldwork was concluded only when new interviews yielded no substantially new codes or categories, ensuring comprehensive coverage of the phenomenon [46]. Interviews typically lasted between 45 and 90 minutes and were conducted in the participants' workshops, homes, or offices to ensure a comfortable and contextually rich environment. To protect confidentiality and strengthen data integrity, all transcripts were meticulously anonymized immediately after transcription. Additionally, role-based codes (e.g., "Sculptor 1", "Environmental Authority 2") were used to attribute quotes during the reporting phase.

2.4. Data Analysis

All dialogues were recorded (with informed consent), transcribed verbatim, and assessed through rigorous qualitative content analysis in the software ATLAS.ti (version 25). To ensure high investigative rigor and mitigate subjective bias, a hybrid coding strategy combining deductive and inductive procedures was systematically used, allowing for both theory testing and theory building [47].

1. **Deductive coding:** Pre-established concepts related to sustainable value chains, the value paradox, and commons management guided the initial round of coding. Categories such as *market access*, *property rights*, *institutional weakness*, and *scarcity perception* were used to assess how existing theoretical frameworks mapped onto the empirical material collected from Imbabura [11,13,14].
2. **Inductive coding:** Additional, highly specific categories emerged organically from the iterative reading of the transcripts. This generative phase produced situated themes such as *institutional distrust*, *bureaucratic friction*, and the *cultural erosion of artisanal knowledge* among younger generations.

Following the coding cycles, semantic networks and co-occurrence matrices were generated within ATLAS.ti to visualize the complex relationships among the categories. This computational support strengthened the analytical traceability of the interpretation, ensuring that the theoretical conclusions were directly grounded in the qualitative data provided by the interviewees [46,47]. The integration of these perspectives provides a multi-dimensional map of the *Juglans neotropica* value chain, exposing the friction between conservation ideals and everyday economic survival.

3. Results

3.1. Perceived Value and Value Chain Actors

Interviewees described the neotropical walnut value chain as encompassing both timber supply and the extraction of non-timber products, reflecting its profound socioeconomic duality (Figure 2). Several respondents emphatically stated that a significant portion of the total generated profitability is almost exclusively captured by an informal network of intermediaries. The following testimony from a local authority intimately familiar with the chain's evolution illustrates this dynamic:

> *"There was a natural supply. Legal restrictions did not initially prevent us from working with this species. But when shortages began here, we had to start looking for basic material elsewhere. Now,*

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an entire generation is lost because the artisanship is simply not yielding the income that parents see as a viable future for their children. Rebuilding that trust is difficult" **(E21)**.

Participants also emphasized the continued (albeit threatened) importance of non-timber products, especially nuts (toctes), natural dyes, and traditional sweets such as *nogadas*.

As one traditional artisan lamented regarding the loss of these historical practices:

"Many things come from the walnut tree. First there were the nogadas, because Ibarra has a whole identity tied to them. The nut was also heavily used to dye clothes and regional fabrics, and from there, other specific handicrafts emerged naturally. Today, we are losing all of that because the trees are just chopped for blocks" **(E13)**.

Interviewees consistently noted that environmental authorities (e.g., MAATE) play an essential but often complicated regulatory and advisory role in permit processing and legal harvesting. This generational disconnect is reflected in a master artisan's reflection:

"My mother taught many people in the village. I also taught my children; they still help me sometimes, but honestly, they want to study something else. They see the struggle with the wood scarcity and the low pay, and they prefer to dedicate themselves to something completely different. It's sad, but it's the reality" **(E2)**.

Its distinctive grain, unpredictable color variation, and unique aroma reinforce its symbolic and monetary pre-eminence in San Antonio de Ibarra.

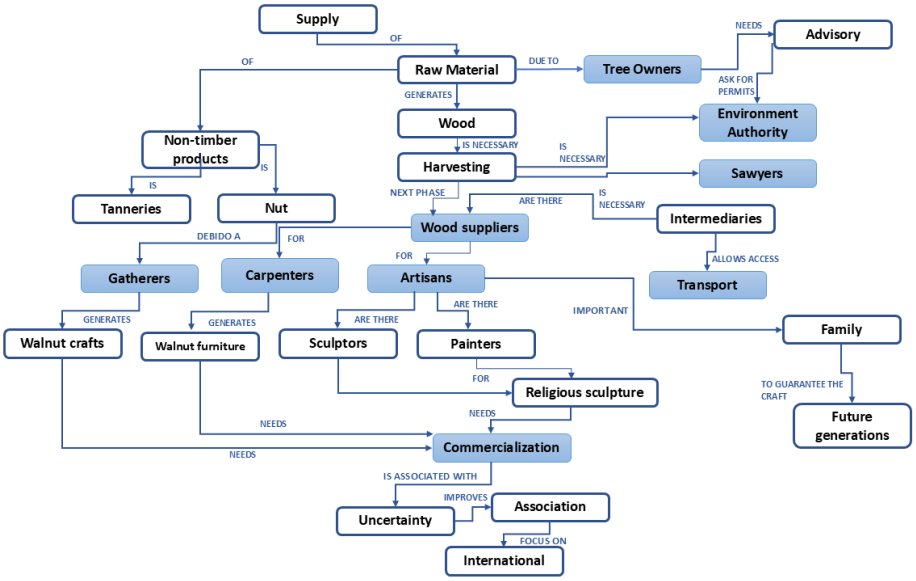

Figure 2. Relationships among value chain actors and perceived roles.

3.2. Perceptions of Basic Material Sources

Interview narratives consistently linked raw material sourcing to an alarming trajectory of growing scarcity and spatial dislocation (Figure 3); older respondents reported that large-diameter walnut timber was formerly abundant in the immediate peri-urban and rural areas of the Imbabura region. One experienced sawyer clearly explained the logistical shift:

"If a truck transports wood we are talking about loading 1000 or 1200 boards. Where are they going to get 1200 boards from here? It's impossible. Before, we had enough walnut heartwood locally in San Antonio, but now it is almost impossible to get a full load. We have to go to other distant cantons just to find fragments because here it is completely gone" **(E1)**.

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Participants also frequently observed that timber harvesting and eventual use are heavily conditioned by environmental permits and normative controls. This frustrating dynamic was summarized candidly by a transporter deeply embedded in the supply logistics:

> *"The problem is that we depend entirely on those who bring the heartwood. Yet, often they do it through illegal or informal channels because getting the true MAATE permit is a massive headache. That makes the material more expensive with bribes, and we the artisans end up earning much less"* **(E4)**.

At the same time, many respondents highlighted the pressing and immediate need for targeted afforestation programs and sustainable production initiatives expressly focused on *Juglans neotropica*. Institutional support remains a glaring deficit, as one participating public environmental authority acknowledged:

> *"We try to promote reforestation programs with Andean walnut, but there is still a profound lack of commitment from the independent artisans and the local authorities to maintain the young plantations. Without long-term follow up, these initial plantings fail, and people lose hope in the system entirely"* **(E5)**.

Taken together, these widespread perceptions reveal a generalized, systemic concern regarding steadily declining unprocessed material availability.

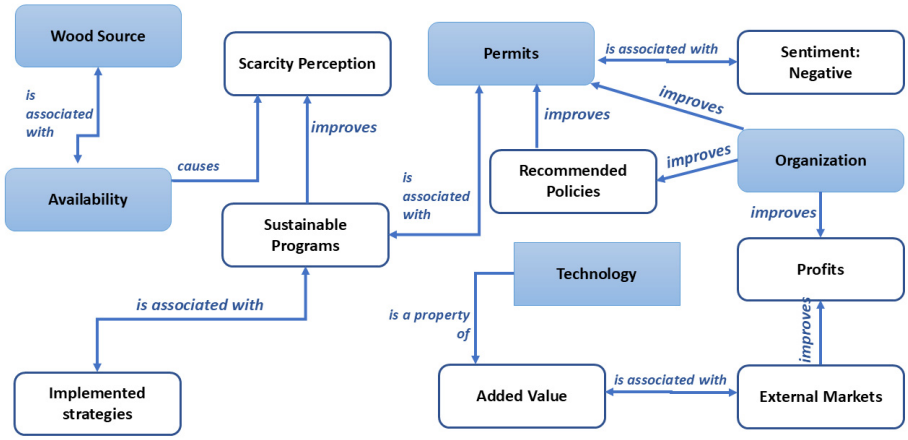

Figure 3. Relationships between basic material sources and perceived selection criteria.

3.3. Information Asymmetry and Disconnected Governance

A recurrent theme throughout the qualitative analysis was the acute disconnect between state-level environmental regulations and the daily operational realities of the rural artisans and farmers in Imbabura. Smaller artisans argued that the burden of proof and the associated financial costs for securing legal origin certificates disproportionately impact them, while well-capitalized intermediaries easily bypass these restrictions (Figure 4).

An experienced environmental authority recognized this pervasive issue, pointing out the lack of coordinated municipal support and community-level agroforestry initiatives:

> *"The condition for exploiting a native species is that it must meet a minimum cutting diameter and guarantee a reserve tree to ensure regeneration. But that is simply never fulfilled because no functional management or replanting programs exist. The Technical University could lead these projects, linking communities, parish boards, and the municipality to insert the species into urban parks, but instead, they are paradoxically planting malignant exotic species like the African tulip"* **(E20)**.

The perception is that the regulatory apparatus is fundamentally broken or deeply biased, further eroding any residual trust in state-led conservation. A senior sculptor from San Antonio de Ibarra candidly expressed this collective grievance:

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"The problem is that for the big exporting companies, it's a free pass. They grease the Ministry wheels, pay the officials, and extract all the timber they want. But if a local poor farmer brings in a single small log to sell to an artisan, they confiscate it immediately. There is no authority here defending the artisan; Imbabura has become a complete disaster in that regard" **(E18)**.

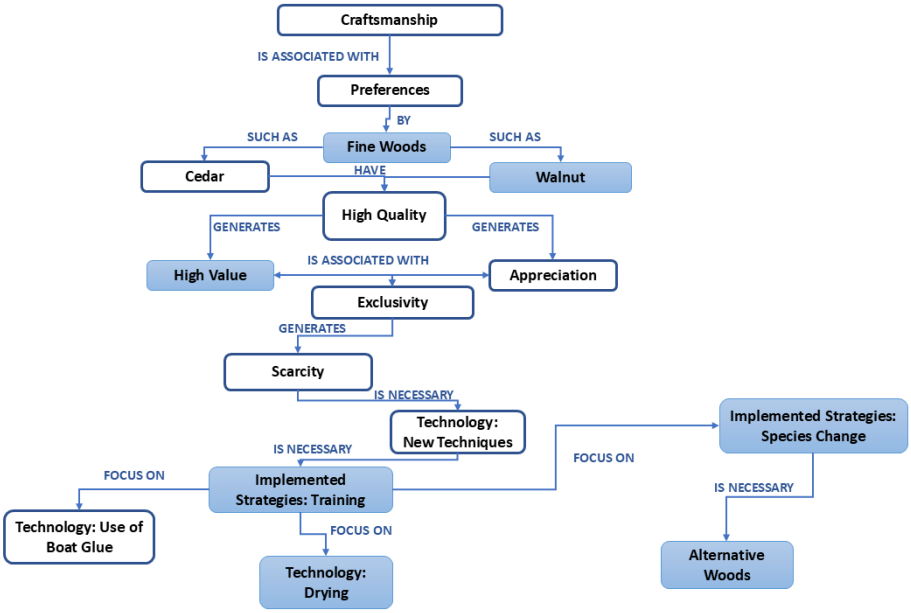

Figure 4. Perceived governance asymmetries and institutional barriers reported by value chain actors.

3.4. Cultural Devaluation and the Industrialization Threat

Today, modern automated duplicating machines largely dominate the local market. Because the cost of raw material remains high, mechanized producers actively push to lower the purchasing prices paid to sculptors in order to maintain competitive retail pricing, thereby degrading the socio-economic status of the master artisan. A lifelong woodcarver somberly detailed the financial mechanics of this cultural erasure:

"The problem is that we haven't valued ourselves. The machines came and accelerated everything, eliminating the deep learning process. A young boy learns to use a machine and simply cleans a pre-made figure, charging $15 for a half-day's work. This drastically cheapens the final costs and hurts the true master sculptor, because the external client eventually stops caring if it is carefully handmade or rapidly stamped out by a machine" **(E8)**.

The pressure exerted by industrialized production also has profound intergenerational consequences. The transmission of specialized skills regarding the selection, drying, and carving of *J. neotropica* is thus stagnating. A master artisan emotionally recounted how precarious market conditions deliberately pushed his family away from the traditional trade:

"When I delivered a custom piece historically, the buyers would constantly change the requested color just to exploit us and pay less. My children saw how I suffered, returning home with rejected artwork after working all week without pay. That's precisely why they chose entirely different professions. The young people see the struggle and naturally refuse to endure it" **(E14)**.

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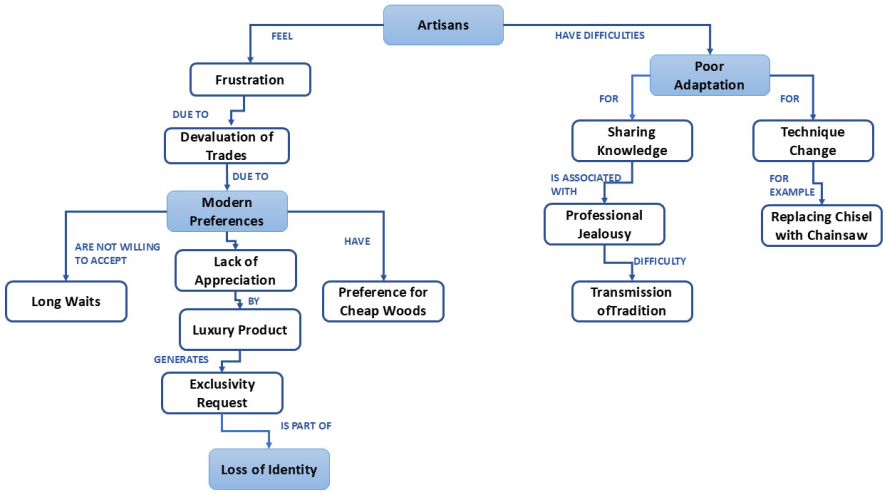

Figure 5. Drivers of cultural devaluation and generational knowledge transfer decline.

3.5. NTFPs and the Unrealized Potential of the "Nogada"

Consequently, *nogada* producers are often entirely marginalized within the broader value chain, struggling to access sufficient volume of high-quality wild nuts.

One of the most recognized local *nogada* producers from a historically rooted family highlighted the systemic limitation of their craft:

> *"Because there is practically no wood left, there are no nuts. If we ever wanted to export to European countries, it would be impossible because we simply cannot offer the persistent quantities they demand. There is no qualified labor, and there is immense local selfishness among the artisans instead of unity. That fragmentation totally prevents us from advancing or exporting our traditional products"* **(E10)**.

A local nursery technician confirmed this institutional bias against attempting the more difficult cultivation of native walnut for standing-forest products:

> *"Honestly, in the governmental nurseries, there is a massive scarcity of many species. You see the exact same four or six easy species repeated in Pichincha, Santo Domingo, and Loja. The technicians already know how to handle the seeds of those common species. Since they want to produce thousands of plants quickly with no germination problems, they completely ignore complex native species like the walnut"* **(E12)**.

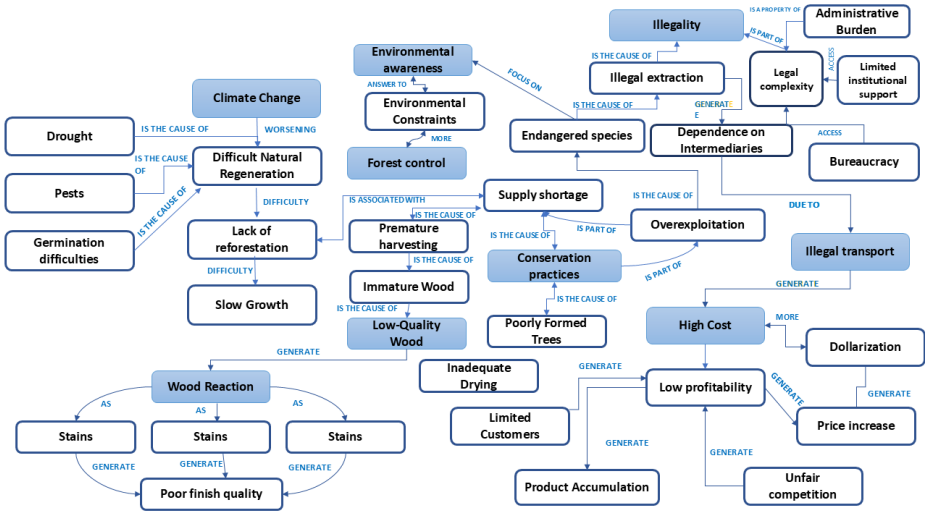

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Figure 6. Barriers to NTFP commercialization and institutional marginalization of nogada producers.

4. Discussion

4.1. The Value Paradox and the Institutional Void in Imbabura

The qualitative findings of this study provide strong empirical confirmation of the *value paradox* previously theorized by Cronkleton et al. [13] and further nuanced in recent literature addressing highly informal timber markets in the Neotropics [11,14,15]. In the case of *Juglans neotropica* in Imbabura Province, the resource's high commercial and cultural value does not translate into effective long-term silvicultural stewardship or meaningful local conservation efforts [1,5,20]. Instead, this exact value acts as a strong catalyst for rapid, uncoordinated extraction [23,36]. Local tree owners, often operating entirely outside of formal cooperative structures and squeezed by severe rural poverty, view the Andean walnut primarily as an immediate short-term cash reserve [14,52,53]. The systemic failure of existing governmental institutions to provide viable legal harvesting pathways fundamentally prevents these stakeholders from recognizing or capturing the tree's true long-term ecological and financial value [7,39,44].

The overwhelming presence of bureaucratic friction (specifically complex permitting procedures and the high transaction costs of legal compliance) creates an institutional void rapidly filled by exploitative intermediaries [13,14,43]. This dynamic is further heavily exacerbated by structural information asymmetries [54]. Artisans and primary producers expressed feeling intentionally alienated from the rule-making processes designed ostensibly to protect the species they intimately rely upon for their daily subsistence [17,21]. As noted critically by one interviewee (E18), the perception that legal restrictions aggressively target small-scale informal users while systematically ignoring industrial extraction destroys the social capital and underlying trust necessary for any functional community-based forestry model [28,39,41]. Consequently, the lack of secure tenure, transparent market pricing, and institutional legitimacy traps *J. neotropica* in an unsustainable cycle of rapid liquidation, effectively driving local genetic erosion and reducing the landscape's overall climate resilience [30,31,33].

4.2. Overcoming Fragmentation: The Imperative for Polycentric Stewardship

Reversing this highly destructive trend requires an immediate and fundamental reconfiguration of the province's environmental governance structure toward polycentric stewardship [18,19]. Moving entirely away from top-down, punitive conservation models that historically marginalize rural landowners, polycentricity actively distributes authority across multiple, overlapping centers of decision-making [27,48,55]. In practical terms for the Andean walnut value chain, this means explicitly acknowledging and integrating local artisanal associations, indigenous community boards, academic institutions and municipal governments directly into the regulatory design process [14,28,39]. Only by formally empowering these decentralized local actors can we begin to reduce transaction costs, minimize the crippling influence of unregulated intermediaries and begin to align forest conservation directly with tangible local economic development [8,43].

Additionally, establishing functional multi-stakeholder platforms specifically dedicated to monitoring and managing *J. neotropica* is vital for facilitating knowledge transfer and technical innovation [13,19,28]. These formalized networks could effectively standardize transparent minimum pricing for legally harvested, certified walnut timber, drastically reducing the extreme market volatility and exploitation currently defining the sector [14,39,41]. Academic institutions, particularly regional universities specializing in agricultural and forestry sciences, must assume a central role in overcoming this fragmentation [29,40]. By leading coordinated capacity-building programs, supplying high-quality, genetically verified seedlings [31,35] and offering extension services in advanced silvicultural techniques, these institutions can actively bridge the crippling gap between theoretical environmental policy and the practical, on-the-ground management needs of the rural artisans and farmers [37,46,56].

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4.3. Silvicultural Interventions and the Restoration of the Walnut Landscape

Even if governance constraints are successfully mitigated through polycentric arrangements, biological and technical barriers remain formidable obstacles to the long-term conservation of *Juglans neotropica* [20,21,36]. The qualitative interviews consistently highlighted the total absence of managed nurseries or structured replanting initiatives specifically targeting this slowly growing, complex native species (E12). Addressing the dramatic spatial dislocation of the timber supply requires urgent, massive investment in scientifically rigorous afforestation and environmental restoration programs across the degraded Andean corridors [5,17,23]. Because the species is exceptionally vulnerable to habitat fragmentation and requires specific microclimatic conditions [1,2,12], these restoration efforts must be highly strategic, utilizing advanced spatial suitability models and cloud-based monitoring to pinpoint optimal planting sites in Imbabura [34,45,51].

Crucially, the success of these long-term restoration initiatives depends intrinsically on incorporating extensive genetic diversity and meticulously identifying resilient seed provenances to withstand the escalating impacts of anthropogenic climate change [29–31]. Without rigorous provenance tracking, any attempt to artificially regenerate *J. neotropica* populations will likely yield individuals highly susceptible to novel pathogens, extreme drought, or shifting temperature regimes [33,35]. Furthermore, practical biophysical interventions, particularly the strict managed exclusion of free-roaming cattle from young plantations, are essential to ensure seedling survival and viable early-stage tree productivity [26,32,50]. Transitioning from reactive, punitive conservation to proactive, community-led silviculture (where local farmers actively manage small-scale, high-value timber plantations) can transform the heavily degraded agricultural frontiers of Imbabura into structurally diverse, highly productive biocultural landscapes [3,5,11,57].

This strategic transition toward proactive landscape restoration must simultaneously involve the deep economic valuation of the associated ecosystem services the standing walnut tree provides, including carbon sequestration, watershed hydrological regulation and intricate soil stabilization on steep Andean slopes [1,19,22]. Implementing localized Payment for Ecosystem Services (PES) schemes tailored precisely to the realities of smallholders in Imbabura could provide the critical, necessary financial bridge, effectively rewarding communities for keeping the trees standing until they reach the optimal biological and financial maturity for highly selective, low-impact harvesting [8,39,44]. As the qualitative interviews consistently demonstrated, without clear, immediate, and tangible financial incentives replacing the foregone revenue of immediate logging, true community commitment to long-term replanting and maintenance will remain difficult to achieve [13,14].

4.4. Financial Valuation Models and Real Options Analysis under Uncertainty

Addressing the persistent value paradox requires moving beyond traditional static financial valuations of *Juglans neotropica* and embracing dynamic economic models, such as Real Options Analysis (ROA) [42]. Classical net present value (NPV) calculations systematically fail to capture the profound strategic flexibility inherent in delaying the timber harvest, especially when managing exceptionally slow-growing, highly valuable neotropical species [23,36,38]. By applying ROA to the decision-making matrices of smallholder farmers in Imbabura, policymakers can robustly quantify the immense hidden financial value of maintaining the standing forest while strictly awaiting optimal future market conditions or the potential implementation of localized carbon credit markets [22,44,50].

Furthermore, this advanced financial modeling directly counters the heavy short-term pressures generated by exploitative intermediaries and informal supply chains [13–15]. When rural landowners are formally equipped with mathematically accurate forecasts regarding how accelerating climate change, shifting genetic resilience, and highly unpredictable future artisanal demand will critically impact the species' absolute market scarcity, their willingness to engage securely in long-term silvicultural stewardship increases dramatically [31,35,52]. The systemic integration of these rigorously derived econometric valuation techniques into regional protected area planning is therefore not merely an abstract academic exercise, but rather a necessary strategic step required to

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structurally incentivize the physical preservation of Imbabura's fragmented, socio-ecologically critical biocultural landscapes [5,45,51].

The ultimate successful deployment of such advanced macro-fiscal mechanisms inevitably depends highly on unprecedented institutional coordination among the Ministry of Environment (MAATE), marginalized provincial governments, and leading regional academic institutions [19,28,41]. Without the explicit, unwavering financial commitment of these macro-level stakeholders to jointly underwrite the initial technical implementation costs of executing ROA strategies, the extremely vulnerable rural communities will inevitably default rapidly back to the familiar, tragically destructive path of rapid, fully unregistered timber extraction simply out of basic sheer economic desperation [11,14,54].

4.5. The Critical Economic Power of NTFPs and Generational Transitions

The qualitative evaluation also profoundly stresses the systemic marginalization of Non-Timber Forest Products (NTFPs) within the broader *Juglans neotropica* value chain. Historically, the extraction of the walnut seeds (toctes) and the subsequent production of natural organic dyes formed the backbone of sustainable family economies in the region [9,10,24]. Currently, these products are entirely relegated to minor cultural novelties, eclipsed by the intense, financially attractive demand for high-value timber blocks [20,23]. Promoting the formal, structured commercialization of toctes and *nogadas* is potentially one of the most effective non-punitive strategies for preserving the remaining wild populations [5–7]. When rural communities generate consistent, meaningful income from the annual nut harvest, the immense financial pressure to prematurely cut the tree for a single, final timber payment is substantially reduced [11,58].

This transition demands a fundamental organizational upgrade among the disparate families currently producing the *nogadas* [14,39]. Forming consolidated, formal cooperatives would enable these small-scale producers to efficiently pool resources, invest strategically in necessary sanitary certifications, and access much larger, premium geographic markets [28,41,54]. Currently, as shown clearly by E10, fragmented production capacity entirely prevents local artisans from fulfilling lucrative international export orders or accessing high-end national gastronomic sectors [43,57]. Beyond strict economics, revitalizing these specific NTFP pathways is central to preserving the fading biocultural heritage of Imbabura [3,19]. As modern industrial machinery displaces the highly specialized manual carving techniques [36,59], actively promoting and protecting the distinct artisanal identity of the surrounding communities becomes a critical defensive mechanism against rapid cultural homogenization [24,48].

However, achieving this revitalization is particularly challenging without explicitly addressing the structural generational disconnect highlighted by multiple master artisans during the phenomenological interviews [46,47]. The continuous economic precarity historically associated with the traditional woodcarving and sweet-making trades acts as a profound deterrent for younger demographics, who logically seek more stable and socially recognized formal employment [13,53]. Strategic educational and cultural interventions, such as formally certifying master craftsmen as legitimate regional heritage instructors or formally integrating traditional supply-chain management into local technical curricula, are urgently needed to ensure that this specialized ecological and artisanal knowledge is successfully transmitted before the older generation entirely retires [37,56].

4.6. Methodological Limitations and Replicability in the Tropical Andes

While this qualitative phenomenological research offers deep, previously unrecorded insights into the socio-institutional realities governing the *J. neotropica* value chain in northern Ecuador, some methodological limitations must be acknowledged [46,47]. The sample size, though robustly achieving theoretical saturation for the specific geographic context of Imbabura and San Antonio de Ibarra (n=21), remains fundamentally localized [5,14]. Consequently, extrapolating these highly specific governance and market dynamics directly to other distinct Andean regions (such as the

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localized artisanal centers in Colombia or Peru) should be approached carefully, recognizing the vast differences in national forestry legislation and cultural trajectory [17,20,21].

Additionally, the inherent reliance on self-reported semi-structured interview data introduces a degree of unavoidable potential recall and social desirability bias, particularly when discussing sensitive, heavily regulated activities like logging and the transportation of legally protected native flora [14,52]. The deep distrust of the state environmental apparatus clearly colored many of the provided responses [11,15]. Despite these known constraints, the strict thematic coding methodology utilized within ATLAS.ti ensured a high degree of analytical transparency and internal validity, successfully anchoring the abstract theoretical framework of the value paradox directly within the concrete lived experiences of the chain's actors [13,28,47]. Future interdisciplinary investigations should seamlessly combine this qualitative understanding with extensive, rigorous quantitative assessments of timber volumes, precise geospatial habitat fragmentation monitoring and localized real options analysis (ROA) to comprehensively evaluate the precise financial viability of various, competing forest management models under shifting climatic parameters [12,42,45,51].

4.7. Strategic Roadmap for Sustainable Value Chain Transformation

Synthesizing the vast ecological [1,20,30], institutional [13,14,28] and cultural [9,10,24] dimensions uncovered in this deeply integrated analysis, we propose a strategic, actionable roadmap for transitioning the *Juglans neotropica* value chain from its current trajectory of rapid depletion toward a model of long-term sustainable management and community empowerment in the Tropical Andes:

1. **Formalize Inclusive Legal Frameworks:** Completely restructure current forestry regulations to drastically lower the bureaucratic barriers and financial transaction costs placed on small rural producers [43,54]. Implement accessible, highly simplified, and heavily digitized permitting systems that explicitly recognize and support traditional agroforestry, actively displacing the informal intermediaries who currently exploit the regulatory burden [14,39].
2. **Promote Community Forestry Enterprises (CFEs):** Facilitate the active creation and structural strengthening of formal local associations composed of tree owners, seed collectors, sawyers, and master sculptors [28,41]. These legally recognized networks can negotiate far better, standardized prices directly with the artisanal demand centers, implement rigorous internal chain-of-custody traceability mechanisms and meaningfully reduce the highly damaging dependency on exploitative transport middlemen [11,48,55].
3. **Elevate NTFPs within Regional Economic Planning:** Systematically prioritize the development, sanitary certification, and targeted marketing of the walnut-derived *nogadas* and natural textile dyes [6,7]. Integrating these historically marginalized products thoroughly into provincial tourism and cultural initiatives can provide the rural stakeholders with the immediate, consistent financial incentive required to preserve the standing trees until absolute silvicultural maturity [9,10,58].
4. **Deploy Geospatial Technology for Ecological Restoration:** Deploy advanced cloud-based remote sensing and spatial analysis algorithms to meticulously map the remaining *J. neotropica* genetic populations and accurately identify optimal, highly suitable sites for massive reforestation across Imbabura [12,45,51]. These efforts must systematically integrate carefully selected resilient seed provenances to ensure long-term population survival amidst accelerating global climate shifts [29–31].
5. **Implement Localized Payment for Ecosystem Services (PES):** Design and execute strong, community-centered PES contracts that directly compensate the rural land-owning families for the critical carbon sequestration and hydrological regulation actively provided by their native walnut trees [8,22,44,50]. This model powerfully corrects the core market failure of the value paradox, realigning short-term individual financial profitability perfectly with long-term regional ecological stability [13,14,19].

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4.8. Contextualization of Findings within Existing Literature

The observations detailed in the qualitative study align strongly with and expand upon several key patterns in the literature. On the forestry product side, participants identified tree owners, intermediaries (suppliers and transporters), independent sawyers and traditional artisans (carvers and sculptors) as the central actors involved in moving raw material from the scattered rural landscape toward high-end carving and urban commercialization [11,13,14]. This structural inequality severely disincentivizes sustainable management at the farm level, as tree owners receive only a fraction of their timber's true market value [14,52]. These auxiliary products remain a core part of the cultural identity of Ibarra and intrinsically link the species to family-based, small-scale artisanal economies [9,10,24]. Positioning such NTFPs prominently within regional and national development agendas is considered critical for balancing biodiversity conservation and rural livelihood goals without strictly resorting to punitive forestry measures [11,49]. In addition to its culinary and decorative uses, the species holds significant unquantified value in local ethnomedical practices, reflecting a deep-seated cultural knowledge of the leaf and bark's medicinal properties [9,24]. The exceptional nutritional density of the tocte nuts further supports their long-standing potential as a staple crop in integrated biocultural landscapes [10,48,58]. While MAATE aims to prevent illegal extraction, intermediaries often manipulate this system to control transport logging and market access, leaving legitimate artisans in precarious legal positions [14]. Creators, such as sculptors, were described not only as primary producers but also as the ultimate guardians of specialized knowledge [46,47]; unfortunately, many expressed deep concern that younger demographic cohorts are increasingly unwilling to endure the strenuous apprenticeship required to continue the trade. Overall, respondents across the entire qualitative sample perceived *Juglans neotropica* as an inherently high-value but increasingly scarce and disputed forest resource [20]. Nevertheless, rising absolute scarcity is steadily reducing access to high-quality material, placing immense pressure on both the artisanal economy and the remaining wild tree populations [23,36,37]. Conversely, current access is highly restricted and spatially dispersed, generating widespread operational concern across every node of the value chain; as the supply radius expands, transport costs scale exponentially, squeezing already narrow profit margins [14,54]. Although such stipulations are ostensibly intended to protect the endangered species [17,21], they are uniformly perceived by rural landowners and artisans as excessively difficult to navigate. This is due to profound procedural complexity, asymmetrical information access, and long, economically unviable waiting times [39]. Under these conditions, the regulations inadvertently penalize formal actors while enriching informal intermediaries [14,43]. In their collective view, such orchestrated efforts could increase future timber availability, dramatically improve transparent communication among agents, and encourage urgently needed technological and organizational innovation [29,35,56]. They highlight the absolute urgency for localized strategies capable of sustaining the Andean walnut value chain over time, integrating spatial planning, silvicultural intervention, and community empowerment [51,54]. While the Ministry of Environment, Water and Ecological Transition (MAATE) mandates specific diameter limits and reforestation ratios for harvesting *Juglans neotropica*, local stakeholders described these policies as structurally asymmetric and difficult to comply with [13,14]. This stark inequality breeds intense frustration and actively disincentivizes formal conservation compliance [14,43,52]. The bureaucratic friction faced by small producers generates a distinct paradox: as legal controls tighten to protect the species [17,21], the informal market actually expands to circumvent the administrative bottleneck. Several interviewees narrated explicit examples where this misalignment effectively decoupled the official conservation strategy from the economic needs of the artisans [28]. Equally important, several artisans expressed deep resentment over how these opaque, top-down governance frameworks historically permitted large-scale industrial logging while heavily penalizing the small-scale, traditional users [15,27,38]. This localized lack of trust severely complicates efforts to establish modern participatory monitoring systems or certified value chains, as stakeholders remain deeply skeptical of institutional motives [14,39]. In addition to ecological scarcity, the traditional Andean walnut value chain is actively deteriorating due to the rapid incursion of mechanized, mass-

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production techniques in San Antonio de Ibarra [5,9,10]. Traditionally, carving *Juglans neotropica* was a highly slow, meticulous process requiring years of specialized apprenticeship [46]. These machines rapidly produce low-cost, structurally identical figures, fundamentally displacing the manual work of master sculptors and homogenizing the final products [37,59]. Participants consistently emphasized that this technological shift has devastating consequences not only for the economic survival of traditional sculptors but also for the intrinsic cultural valuation of the wood itself [24,48]. The economic hardship historically experienced by master artisans acts as a powerful deterrent for the younger generations, who now overwhelmingly opt for formal university education or alternative wage labor in different economic sectors [13,14,53]. Ultimately, these combined economic and technological pressures force the remaining artisans into an unsustainable volume-based production model, further accelerating the local demand for *Juglans neotropica* timber while simultaneously destroying the cultural premium historically attached to handmade artisanal products [23,36,48]. Despite the overwhelming dominance of timber extraction, a small but fiercely resilient subset of the local economy continues to rely entirely on the non-timber products derived from *Juglans neotropica*, specifically the traditional production of *nogadas* (walnut-based sweets) [9,24,58]. These actors face a unique set of challenges characterized by extreme raw material scarcity, as the trees are overwhelmingly felled for timber before they can reach optimal, mature nut-producing age [20,25,30]. The traditional commercialization of the *nogada* remains highly localized and informal, primarily constrained by low technological adoption and a lack of standardized sanitary certifications required for national or international export [11,14,54]. This inability to scale production or access premium geographic indication markets prevents these traditional producers from realizing the true financial potential of the standing walnut tree [6,7,58]. Furthermore, state-sponsored nurseries and local governmental planting programs consistently fail to prioritize *Juglans neotropica* for nut production or agroforestry, instead heavily favoring fast-growing exotic species or generic ornamental trees that are easier to propagate [29,40,55]. This systemic institutional failure to actively support and formalize the NTFP dimension of the *Juglans neotropica* value chain perfectly exemplifies the prevailing value paradox: even though the nuts have the potential to structurally support sustainable livelihoods and effectively justify the conservation of the standing trees, the immediate financial allure and institutional path-dependence of timber extraction consistently outcompete them [8,44,57].

5. Conclusions

This investigation into the *Juglans neotropica* value chain in the Andean highlands of Imbabura Province profoundly emphasizes the immediate conservation urgency surrounding one of South America's most ecologically and culturally significant tree species [1,5,20]. The empirical findings presented confirm that the mere existence of high economic timber value is paradoxically insufficient to guarantee its sustained, responsible management [13]. Currently, deep-seated structural issues characterized by vast information asymmetries, complex and exclusionary bureaucratic barriers and an extremely powerful informal intermediary network systematically prevent small-scale landholders and master traditional artisans from capturing the true financial worth of their natural resources [11,14,54].

Simultaneously, the steady and deliberate marginalization of critical non-timber forest products (NTFPs), specifically the nuts utilized in the highly traditional *nogadas* and natural textile dyes, effectively eliminates the strongest available economic argument for keeping the walnut trees physically standing in highly modified agricultural landscapes [6,7,9,10,24,58]. The ongoing rapid displacement of traditional manual woodcarving techniques by heavily mechanized, high-volume production in San Antonio de Ibarra further drives enormous, unchecked demand for raw material while radically depreciating the cultural premium previously attached to handmade crafts [36,48,59]. These concurrent, complex pressures severely undermine the future viability of the entire artisanal system, consequently strongly dissuading newer generations from continuing the historical trade,

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risking the imminent complete loss of fundamentally specialized ecological and culturally situated knowledge [46,47,53].

Achieving true sustainability ultimately requires a fundamental paradigm shift away from purely punitive regulatory regimes toward proactive, polycentric stewardship [18,19,39]. Implementing sturdy, localized Payment for Ecosystem Services (PES) frameworks, promoting transparent community forestry enterprises (CFEs) through structured legal support and leveraging highly advanced spatial algorithms for massive, genetically informed landscape restoration are no longer optional strategies; they are urgent priorities [8,12,22,29–31,45,51]. The survival of *Juglans neotropica* as a highly distinct cultural icon and an essential keystone component of the fragile Andean cloud forests fundamentally requires that regulatory policies finally bridge the profound gap between theoretical species conservation and the concrete operational needs of the rural populations explicitly depending on it.

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Institutional Review Board Statement: Ethical review and approval were waived for this study, as it involved interviews with adult professionals and key informants sharing expert knowledge in their areas of competence, with no collection of sensitive personal data or risk to participants.

Informed Consent Statement: Verbal informed consent was obtained from all subjects involved in the study prior to data collection.

Data Availability Statement: The data supporting the findings of this study are available within the article.

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
ATLAS.ti	Archiv für Technik, Lebenswelt und Alltagssprache (qualitative data analysis software)
CFE	Community Forestry Enterprise
GAD	Decentralized Autonomous Government (Gobierno Autónomo Descentralizado)
GICFOR	Forest Science Research Group (Grupo de Investigación en Ciencias Forestales)
IUCN	International Union for Conservation of Nature

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MAATE	Ministry of Environment, Water and Ecological Transition (Ministerio del Ambiente, Agua y Transición Ecológica)
NPV	Net Present Value
NTFPs	Non-Timber Forest Products
PES	Payment for Ecosystem Services
ROA	Real Options Analysis
UNESCO	United Nations Educational, Scientific and Cultural Organization
UTN	Universidad Técnica del Norte

Appendix A

Appendix A.1

Table A1. Characterization of the Interviewees.

No.	Actor Type	Coding
E1	President of Ibarra Sawmills	Sawyer 1
E2	Sculptor	Sculptor 1
E3	Transporter	Transporter
E4	Sawyer, Grandson of Sculptor, Intermediary	Sawyer 2
E5	MAATE Technician	Environmental Authority 1
E6	*Nogadas* Artisan	Artisan 1
E7	MAATE Technician	Environmental Authority 2
E8	Sculptor	Sculptor 2
E9	Sculptor, Intermediary	Merchant 1
E10	Sculptor	Sculptor 3
E11	Sculptor	Sculptor 4
E12	Forest Restoration Projects Technician	Environmental Authority 3
E13	*Nogadas* Artisan	Artisan 2
E14	Sculptor	Sculptor 5
E15	Sculptor	Sculptor 6
E16	Academic Researcher	Academic
E17	*Nogadas* Artisan	Artisan 3
E18	Handicrafts Merchant	Merchant 2
E19	MAATE Technician	Environmental Authority 4
E20	President of the National College of Forest Engineers	Leader of the forestry guild
E21	President of GAD San Antonio de Ibarra	Authority of GAD San Antonio de Ibarra

Appendix B. Interview Script.

I. Introduction and Ethical Consent

1. "Good morning/afternoon. We are conducting a study on the sustainability of the Andean walnut (*Juglans neotropica*) value chain in Imbabura. Our goal is to understand the tensions between conservation, wood utilization, and traditional fruit use."

2. **Consent:** "Your participation is voluntary and anonymous. Data will be used solely for academic purposes. Do you agree to proceed?"

II. Actor Profile and Value Chain Role

1. **Role Identification:** "How would you describe your primary activity? (e.g., Sawyer, Sculptor, Nogadas Artisan, Merchant, Official)."

2. **Experience:** "How many years have you been working with Andean walnut? Has your role changed over time?"

III. The 'Value Paradox': Timber vs. Non-Timber Uses

1. **Resource Competition:** "In your opinion, is it more profitable today to cut the tree for timber or to preserve it for the annual 'tocte' (nut) harvest? Why?"

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2. **Trade-offs:** "Have you noticed a decline in nut availability due to increased logging? How does this affect local traditions like 'nogadas' production?"

3. **Market Pressure:** "Does the high price of walnut wood encourage premature harvesting of young trees?"

IV. Sourcing, Legality, and Scarcity

1. **Perception of Scarcity:** "How has the availability of walnut wood changed compared to 10 or 20 years ago? Is it harder to find large logs?"

2. **Regulatory Impact:** "How do current environmental regulations and permits (MAATE) affect your work? Do they encourage conservation or create barriers?"

3. **Informality:** "Is the 'informal' transport of wood common due to bureaucratic difficulties? How does this impact the final cost?"

V. Cultural Heritage and Intergenerational Transfer

1. **Succession:** "Are young people in your community interested in learning this trade (carving/processing)? If not, why?"

2. **Knowledge Sharing:** "Is there a culture of sharing techniques among artisans, or do you perceive a level of professional jealousy or secrecy?"

3. **Technology vs. Tradition:** "How has the introduction of modern tools (e.g., chainsaws) changed the traditional quality of the work?"

VI. Commercialization and Power Dynamics

1. **Price Stetting:** "Who determines the price of the wood or the final artwork? Do you feel you have bargaining power?"

2. **Intermediaries:** "What role do intermediaries play? Do they facilitate the market or capture most of the profit?"

3. **Markets:** "Where are your products sold? (Local, National, International). Have consumer preferences changed?"

VII. Solutions and Governance

1. **Associativity:** "Would you be willing to join a cooperative or guild to improve management and sales? What has stopped this from happening so far?"

2. **Policy Recommendations:** "What specific actions should local authorities (GADs) or the Ministry (MAATE) take to save the Andean walnut?"

3. **Sustainability Vision:** "What is your vision for the future of this trade? What needs to happen for the Andean walnut to survive?"

VIII. Closing

1. **Open Floor:** "Is there anything else crucial about the walnut chain that we haven't discussed?"

2. **Feedback:** "Would you be interested in seeing the final results of this study?".

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