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Livelihood Contributions and Sustainability of Non-Timber Forest Products in Community Forest Areas of Kenya

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ABSTRACT: Non-timber forest products (NTFPs) constitute a critical yet underquantified component of rural livelihoods in Kenya's forest-adjacent communities. Despite a growing global literature on NTFP economics, systematic evidence on the diversity, economic value, and governance conditions enabling sustainable NTFP use in Kenyan forests remains fragmented, and no prior study has examined these dimensions jointly across contrasting forest landscapes using a common methodology. This study assessed NTFP species diversity, household income contribution, and harvest sustainability across two ecologically distinct forest landscapes: Mount Kenya Forest Reserve (MKFR) and the Cherangany Hills Forest Complex (CHFC). Using a mixed-methods design combining household surveys ($n = 487$), species diversity transects, market value assessments, and semi-structured key informant interviews ($n = 42$), we document 94 NTFP species spanning 47 families actively harvested by forest-adjacent communities. NTFPs contributed a mean of 28.4% (SD = 11.7%) of total annual household income, with medicinal plants, wild edibles, and craft materials representing the most economically significant categories. Women-headed households derived a significantly higher proportion of income from NTFPs than male-headed households (34.1% versus 24.8%; $p < 0.001$). Sustainability assessments using a modified Harvest Pressure Index (HPI) identified 23 species under moderate-to-critical harvest pressure. Governance analysis revealed that membership in Community Forest Associations (CFAs) significantly predicted adoption of sustainable harvest practices (OR = 2.87, 95% CI: 2.06–3.99, $p < 0.001$). These findings have direct implications for Kenya's Community Land Act (2016), the Forest Conservation and Management Act (2016), and for NTFP integration into Payment for Ecosystem Services (PES) frameworks under Kenya's emerging green economy strategy.

KEYWORDS: Non-timber forest products; Kenya; community forestry; livelihoods; forest governance; Mount Kenya; Cherangany hills; sustainability; NTFP valuation

1. Introduction

Non-timber forest products (NTFPs) are biological materials other than timber harvested from forests for food, medicine, fiber, resins, and ornamental use, that are estimated to support the livelihoods of over 1.6 billion people worldwide, particularly in tropical and subtropical Africa, where formal employment opportunities are limited and social safety nets are weak [1, 2]. In such settings, NTFPs commonly provide food security buffers during lean seasons, cash income from local and regional trade, and raw material for traditional medicine and craft production [2, 3].

In Kenya, an estimated 3.5 million people live within five kilometers of major forest blocks and depend, to varying degrees, on forest resources including NTFPs, for subsistence, income, and cultural practice [4]. Kenya's forest estate covers approximately 45,426 km² (8% of national land area) across several tenure categories, including government forest reserves administered by the Kenya Forest Service (KFS), community lands governed under the Community Land Act (2016), and private and trust land forests. Despite this dependence, NTFP use has historically been treated as a peripheral concern within national forest policy, which has instead prioritized timber production, watershed protection, and biodiversity conservation [5, 6]. Critically, systematic, quantitative evidence on NTFP species diversity, household economic contribution, and the governance conditions that enable or undermine, sustainable harvest remains fragmented for Kenya's forest landscapes, and no study to date has jointly examined these dimensions across contrasting montane forest systems using a consistent methodology. This gap constrains the ability of policymakers to design evidence-based NTFP interventions under Kenya's current forest governance and green economy reforms.

The 2016 Forest Conservation and Management Act (FCMA) marked a watershed in Kenya's forest governance, legally recognizing community rights to access and benefit from forest resources through participatory forest management (PFM), institutionalized primarily through Community Forest Associations (CFAs). PFM and CFAs have created new opportunities for formalizing NTFP use rights and embedding sustainable harvest norms within community-level governance [7, 8]. However, implementation has been uneven, and whether CFA membership translates into improved sustainability outcomes and equitable benefit distribution particularly for women and other marginalized groups who are often the most intensive NTFP users, remains poorly documented [8, 9].

Addressing this evidence gap is timely given two convergent policy developments. Kenya's updated Nationally Determined Contribution (NDC) under the Paris Agreement commits to 30% forest cover by 2032 and identifies community-based forest management as a key implementation mechanism [10, 11]. At the same time, Kenya's emerging green economy strategy identifies NTFPs including medicinal plants, wild honey, and craft materials, as priority value chains for rural livelihood diversification [12]. Rigorous evidence on NTFP diversity, economic value, and sustainability is therefore essential to inform both the conservation and development dimensions of these policy agendas [12, 13].

To guide this assessment, we adopt the conceptual framework shown in Figure 1, linking NTFP diversity and ecological condition, household livelihood use, forest governance, and harvest sustainability outcomes, with household- and landscape-level characteristics as moderating factors. This framework distinguishes the present study from prior Kenyan NTFP research, which has generally examined diversity, livelihood contribution, or governance in isolation, and rarely across more than one forest landscape using a common methodology [13].

By integrating species-level diversity data, household income analysis, a quantitative harvest-sustainability index, and qualitative governance data within a single mixed-methods design applied to two ecologically and institutionally distinct forest landscapes, this study provides the first landscape-comparative, multi-method evidence base linking NTFP governance to measurable sustainability outcomes in Kenya.

Guided by this framework, the study aims to assess the diversity, utilization, economic contribution, and sustainability of NTFPs in two contrasting forest landscapes in Kenya. Specifically, it (i) documents NTFP species diversity and use-value; (ii) quantifies the contribution of NTFPs to household income and its variation across gender and wealth groups; (iii) assesses harvest sustainability using a modified Harvest Pressure Index (HPI); and (iv) evaluates the influence of participatory forest management and CFA membership on adoption of sustainable harvest practices. The findings are intended to inform evidence-based forest management policy and sustainable rural development strategy in Kenya.

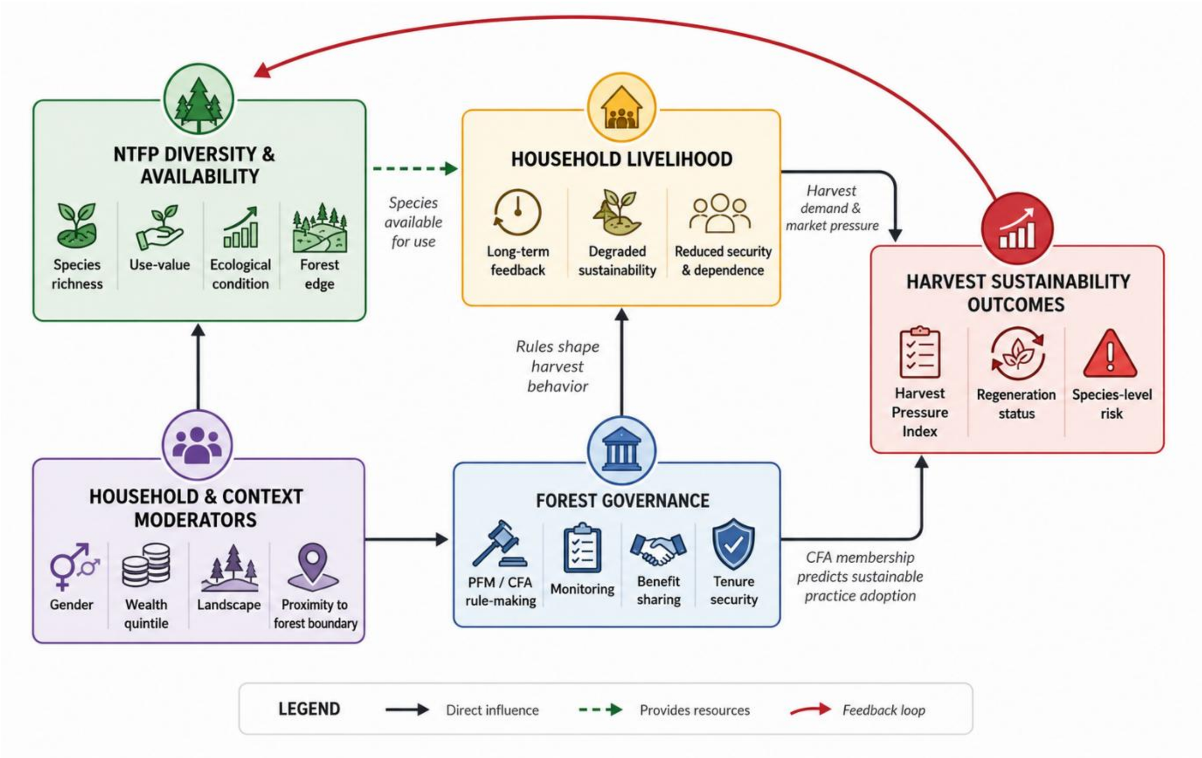

Figure 1. Conceptual framework linking NTFP diversity, household livelihood use, forest governance, and harvest sustainability outcomes, moderated by household and landscape context (Arrows indicate hypothesized directions of influence tested in this study; the dashed feedback arrow indicates the long-term risk that declining sustainability erodes future NTFP diversity and use-value).

2. Materials and Methods

2.1. Study Area.

This research was conducted across two contrasting montane forest landscapes in Kenya (Figure 2), selected to capture variation in ecological conditions, governance arrangements, and socioeconomic setting. Landscape 1, the Mount Kenya Forest Reserve (MKFR), comprises communities bordering a large government-managed forest reserve on the northeastern and eastern slopes of Mount Kenya, characterized by mid- to high-elevation terrain and relatively high rainfall; the forest is jointly managed by the national forestry authority and multiple CFAs under PFM arrangements. Landscape 2, the Cherangany Hills Forest Complex (CHFC), comprises communities adjacent to a montane forest mosaic of indigenous forest, plantations, and community lands; this landscape is a key regional water catchment and supports high biodiversity, including endemic and threatened medicinal plant species. In both landscapes, local communities practice mixed agropastoral livelihoods combining smallholder crop production, livestock rearing, forest resource use, and informal off-farm income activities, with varying degrees of dependence on forest resources for subsistence and income generation.

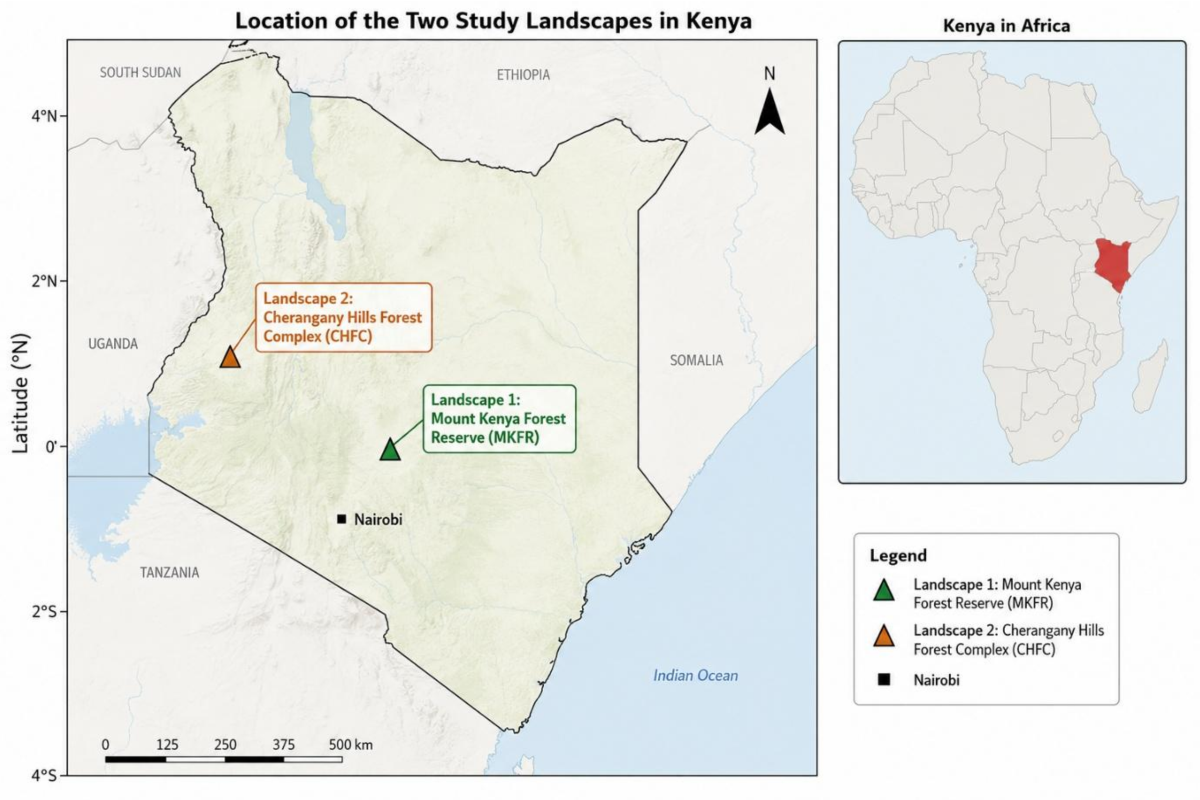

Figure 2. Location of the two study landscapes.

2.2. NTFP Species Diversity Assessment.

To document NTFP species diversity, 120 vegetation survey plots (60 per landscape) were established using a stratified random design, with strata defined by elevation and forest management zone (participatory forest management area, protected core zone, and forest–agriculture interface). Each plot contained nested circular subplots for trees (15 m radius), shrubs (7.5 m radius), and herbs/ground flora (2.5 m radius). All vascular plants recorded were identified to species level, with voucher specimens deposited in a national herbarium for verification and reference. NTFP status was confirmed through published literature, ethnobotanical interviews, and national plant-use and regulatory databases. Species diversity was measured using the Shannon–Wiener index (H′), and compositional overlap between landscapes was measured using Sørensen's similarity coefficient. A use-value index (UVI), based on the number of use categories reported per species, was also calculated for each species following standard ethnobotanical methods [14, 15] to identify the most culturally and economically important NTFPs.

2.3. Household Survey.

A structured household survey was administered between March and September 2023 to assess NTFP collection patterns, livelihood contributions, and governance perceptions in both landscapes. Using two-stage cluster sampling, villages selected proportionally, households randomly sampled within villages, 487 households were surveyed. The questionnaire covered household characteristics, NTFP harvest and use, income sources, and perceptions of forest governance, including CFA participation. NTFP income combined the value of subsistence use and market sales at prevailing local prices. All tools were pre-tested, and trained enumerators administered the survey to ensure data quality.

2.4. Harvest Sustainability Assessment.

Harvest sustainability was assessed for the 30 most commercially important NTFP species using a modified Harvest Pressure Index (HPI). The HPI is the ratio of estimated annual harvest volume to estimated sustainable yield: harvest volume was derived from household survey data aggregated to the landscape level, and sustainable yield was derived from species-specific productivity data collected in vegetation plots, supplemented where local data were unavailable by published literature values. HPI scores were classified as low (< 0.75), moderate-to-high (0.75–1.0), or critical (> 1.0, harvest exceeding estimated sustainable yield). For each species, annual productivity was estimated from repeated measurements of marked plants ($n = 30$ per species where feasible) and scaled to the landscape level using plot-based density data. Harvest fraction (share of available product harvested) and regeneration status (share of harvested populations with adequate natural regeneration) were assessed as complementary indicators.

2.5. Key Informant Interviews.

Forty-two semi-structured key informant interviews (KIIs) were conducted with purposively selected stakeholders in five categories: (i) KFS rangers and forest managers ($n = 10$); (ii) CFA officials and members ($n = 14$); (iii) NTFP traders and processors ($n = 8$); (iv) traditional healers and cultural practitioners ($n = 7$); and (v) county government officials responsible for natural resource management ($n = 3$). Interviews lasted 50–100 minutes, were conducted in Kiswahili or English with simultaneous interpretation as needed, and were audio-recorded with informed consent. Transcripts were analyzed using thematic analysis following Braun and Clarke [16], combining deductive (sustainable livelihoods framework, common-pool resource theory, feminist political ecology) and inductive coding. Inter-rater reliability was assessed using Cohen's kappa ($\kappa = 0.81$). ATLAS.ti version 23 was used for qualitative data management [17].

2.6. Statistical Analysis.

All quantitative analyses were conducted in R version 4.3.2. Descriptive statistics summarized NTFP diversity and household income contributions. Because income shares were non-normally distributed (Shapiro–Wilk $p < 0.001$), group differences by gender, wealth quintile, and landscape were tested using Mann–Whitney U and Kruskal–Wallis tests. Wealth quintiles were derived from a principal components analysis of household asset variables. Predictors of sustainable harvest practice adoption (a binary outcome) were modeled using multilevel binary logistic regression, with village specified as a random effect and key sociodemographic variables included as covariates. Significance was set at $\alpha = 0.05$ throughout. Spatial patterns in NTFP harvest zones and forest cover change were mapped in QGIS 3.32 using Sentinel-2 imagery from 2018 and 2023.

3. Results

3.1. NTFP Species Diversity and Functional Composition.

A total of 94 NTFP species from 47 families were recorded as actively harvested across both landscapes (Table 1). Species richness was higher in CHFC (78 species) than MKFR (67 species), though the two landscapes shared 51 species (Sørensen's coefficient = 0.60), reflecting broad overlap in montane forest flora. Shannon–Wiener diversity was 3.61 (MKFR) and 3.84 (CHFC), indicating high functional diversity in both landscapes. Medicinal plants were the largest functional category (n = 38 species, 40.4%), followed by wild edible plants (n = 24, 25.5%), craft and fiber materials (n = 17, 18.1%), gums, resins, and other products (n = 11, 11.7%), and wild honey and bee products (n = 4, 4.3%).

Table 1. NTFP species richness by functional category and landscape.

Functional Category	MKFR (n)	CHFC (n)	Shared (n)	Total (n)
Medicinal plants	30	35	27	38
Wild edible plants	18	21	15	24
Craft & fiber materials	12	14	9	17
Wild honey & bee products	4	4	4	4
Gums, resins & other	3	4	2	11
Total species	**67**	**78**	**51**	**94**
Shannon–Wiener H′	**3.61**	**3.84**	—	—

Note. MKFR = Mount Kenya Forest Reserve; CHFC = Cherangany Hills Forest Complex. Totals exceed sum of shared species due to landscape-specific species.

The ten species with the highest use-value indices (UVI) spanned five functional categories. Prunus africana (African cherry/pygeum), valued for both medicinal bark and commercial export, recorded the highest UVI (0.84), followed by Urtica massaica (stinging nettle; 0.79), Warburgia ugandensis (pepper-bark tree; 0.77), and Carissa spinarum (conkerberry; 0.74). Eight of these ten species occur predominantly in the forest understory or at the forest edge, indicating that community access to the most valuable NTFPs depends directly on the ecological condition of the forest boundary zone and the rules governing entry and extraction there. Fourteen of the 94 harvested species were recorded exclusively in the protected core zone, where community access is formally prohibited. Key informant interviews confirmed harvest from the core zone for at least nine of these species, driven by scarcity in the accessible buffer zone, indicating that gaps in boundary enforcement carry conservation consequences beyond the immediate governance question [18, 19].

3.2. Household NTFP Income Contributions.

Across the full sample, NTFPs contributed a mean of 28.4% (SD = 11.7%) of total annual household income (Table 2). Income share was significantly higher in CHFC (32.1%, SD = 12.4%) than MKFR (25.1%, SD = 10.3%; Mann–Whitney U, $p < 0.001$), and significantly higher in female-headed households (34.1%, SD = 13.2%) than male-headed households (24.8%, SD = 10.6%; $p < 0.001$). The higher NTFP income share in female-headed households reflects both greater dependence on forest resources in the absence of alternative income sources and women's specialized knowledge of medicinal plant and wild food harvesting, consistent with findings from comparable East African contexts [20–22]. By wealth quintile, NTFP income share declined from 41.6% in the poorest quintile to 14.2% in the wealthiest (Kruskal–Wallis H = 187.4, df = 4, $p < 0.001$), confirming the safety-net function of NTFPs for the most economically vulnerable households [36]. Medicinal plants were the highest-value category in both landscapes (38.3% of total NTFP income), followed by wild edibles (24.7%), craft materials (18.9%), wild honey (11.4%), and other products (6.7%). Overall, 61.4% of harvested NTFP volume (by value) was sold rather than home-consumed; medicinal plants had the highest commercialization ratio (79.3% sold), reflecting active regional and national herbal medicine markets. NTFP income peaked during the two main dry seasons (January–February and July–August), when agricultural income was lowest, confirming a counter-cyclical safety-net role [23, 24]. In 73 households (15.0%), NTFPs accounted for more than half of annual income; this sub-group was characterized by proximity to the forest boundary (< 1 km), female household headship, and absence of formal employment.

Table 2. NTFP income share (%) and logistic regression predictors of sustainable harvest practice adoption.

Variable	NTFP income share (%)	OR	95% CI lower	95% CI upper	p-value
Full sample	28.4 (11.7)	—	—	—	—
Landscape 1 (MKFR)	25.1 (10.3)	Ref.	—	—	—
Landscape 2 (CHFC)	32.1 (12.4)	1.43	1.07	1.92	0.015
Female-headed HH	34.1 (13.2)	1.61	1.19	2.18	0.002
Male-headed HH	24.8 (10.6)	Ref.	—	—	—
Poorest wealth quintile	41.6 (14.1)	—	—	—	—
Wealthiest wealth quintile	14.2 (6.8)	—	—	—	—
CFA membership	—	2.87	2.06	3.99	< 0.001
Tenure security perception	—	1.74	1.38	2.20	< 0.001
Market pressure (commercial)	—	0.58	0.44	0.77	< 0.001

Note. OR = odds ratio from multilevel binary logistic regression; HH = household; CFA = Community Forest Association; SD in parentheses for income share data. All ORs adjusted for age, education, wealth quintile, and landscape. Policy-relevant interpretation: the gradient from 41.6% (poorest quintile) to 14.2% (wealthiest quintile) shows NTFP dependence functioning as an inverse wealth indicator; targeting NTFP value-chain support to the poorest quintile and female-headed households, rather than distributing support uniformly, would concentrate benefits where safety-net dependence is greatest.

3.3. Harvest Sustainability Assessment.

Of the 30 species assessed, 23 (76.7%) had HPI values above 0.75 (moderate-to-critical harvest pressure), and 11 (36.7%) exceeded HPI = 1.0, indicating harvest rates above estimated sustainable yield (Table 3). Critical-pressure species included Prunus africana (HPI = 1.84), harvested for both local medicine and commercial export to European pharmaceutical markets; Warburgia ugandensis (HPI = 1.61), a priority medicinal tree increasingly targeted by urban herbal traders; and Ocotea usambarensis (HPI = 1.39), harvested for incense and perfume material. Three species, *Hagenia abyssinica, Nuxia congesta, and Cassipourea malosana*, showed critical pressure in both landscapes, marking them as immediate conservation priorities. Regression analysis of landscape-level HPI scores (n = 30 species) identified market commercialization ratio ($\beta = 0.61$, $p < 0.001$), accessibility from the forest boundary ($\beta = 0.44$, $p = 0.002$), and slow natural regeneration rate ($\beta = 0.38$, $p = 0.007$) as the strongest predictors of harvest pressure. Species with high medicinal use-value were significantly more likely to face critical pressure than species used primarily as wild foods (OR = 3.14, $p = 0.018$). Seven of the 11 critical-pressure species showed inadequate natural regeneration, with mean seedling density below 20% of reference (unharvested) plots.

Table 3. Harvest Pressure Index (HPI) for the 15 most commercially important NTFP species.

Species	Common Name / Use	HPI	Regen.	Landscape	Status
Prunus africana	African cherry / medicinal bark, export	1.84	Poor	Both	Critical
Warburgia ugandensis	Pepper-bark tree / medicine	1.61	Poor	Both	Critical
Ocotea usambarensis	Camphor tree / incense, perfume	1.39	Moderate	CHFC	Critical
Hagenia abyssinica	African redwood / anthelmintic	1.28	Poor	Both	Critical
Nuxia congesta	Wild elder / craft, medicine	1.19	Poor	Both	Critical
Cassipourea malosana	Pillarwood / craft timber, medicine	1.14	Moderate	Both	Critical
Urtica massaica	Stinging nettle / wild vegetable, medicine	0.94	Adequate	Both	High
Carissa spinarum	Conkerberry / fruit, medicine	0.88	Adequate	MKFR	High
Ekebergia capensis	Cape ash / bark medicine	0.82	Moderate	Both	High
Cornus volkensii	Mountain dogwood / craft wood	0.78	Adequate	CHFC	High
Harungana madagascariensis	Orange milkwood / resin, medicine	0.69	Adequate	Both	Moderate
Acacia abyssinica	Acacia / gum, craft	0.61	Good	MKFR	Moderate
Apis mellifera monticola	Mountain honey bee / wild honey	0.54	Good	Both	Moderate
Rubus apetalus	African raspberry / wild fruit	0.41	Good	Both	Low
Physalis peruviana	Cape gooseberry / wild food	0.28	Good	CHFC	Low

Note. HPI = Harvest Pressure Index (> 1.0 = critical; 0.75–1.0 = high; 0.50–0.75 = moderate; < 0.50 = low). Regen. = natural regeneration status in harvested populations. MKFR = Mount Kenya Forest Reserve; CHFC = Cherangany Hills Forest Complex. Policy-relevant interpretation: all six species under the most severe pressure (HPI ≥ 1.14) are medicinal species with active commercial trade, confirming that commercial medicinal-plant trade, not subsistence use, is the primary driver of unsustainable harvest; regulatory attention should prioritize trade-chain oversight over blanket harvest restrictions.

3.4. Governance Predictors of Sustainable Harvest Practices.

CFA membership was the strongest positive predictor of sustainable harvest practice adoption, including seasonal harvest restrictions, size-selective harvesting, and replanting, after controlling for age, education, wealth quintile, proximity to forest, and landscape (OR = 2.87, 95% CI: 2.06–3.99, $p < 0.001$; Table 2). CFA members were also more likely than non-members to report awareness of species-level NTFP provisions in their community forest management plans (61.3% versus 18.7%; $\chi^2 = 94.7$, $p < 0.001$). Tenure security perception was positively associated with sustainable practice adoption (OR = 1.74, 95% CI: 1.38–2.20, $p < 0.001$), while self-reported market pressure to increase commercial harvest volumes was negatively associated with it (OR = 0.58, 95% CI: 0.44–0.77, $p < 0.001$).

Thematic analysis of key informant interviews identified three primary governance mechanisms through which CFAs influence NTFP sustainability. First, harvest rule-making: 22 of 34 CFA units in the study area had articulated NTFP-specific bylaws in their management plans, including seasonal bans for fruit collection, minimum diameter-at-breast-height (DBH) thresholds for bark harvesting, and quotas for commercial collection; KFS rangers consistently reported easier rule enforcement in areas with active CFAs. Second, monitoring and sanctioning: CFA-organized forest patrols (reported in 19 of 34 units) were an important deterrent to commercial over-harvesting, particularly for high-value medicinal species; a CFA chairperson in the MKFR landscape described a community-led eviction of an unlicensed bark harvester operating at night as an example of effective collective action. Third, benefit-sharing: CFAs negotiating formal NTFP use agreements with KFS channeled a portion of collection fees into community development funds, creating positive incentives for rule compliance among members [25, 26].

Notwithstanding these positive governance effects, qualitative data also revealed significant limitations in CFA effectiveness. Women constituted only 31.4% of CFA membership on average and only 14.2% of CFA leadership positions, despite being the primary NTFP harvesters in both landscapes. Female key informants consistently reported exclusion from rule-making processes and inadequate representation of women-dominant NTFP use categories in management plans. This institutional gender gap has direct equity and sustainability implications, as management plans that do not reflect women's knowledge and priorities are likely to miss key conservation risks and livelihood concerns [27, 28]. Governance reforms aimed at achieving gender-equitable representation within CFAs are therefore essential alongside technical NTFP management interventions.

4. Discussion

4.1. NTFP Diversity and the Significance of the Forest Edge.

The 94 NTFP species documented here represent one of the most comprehensive landscape-scale inventories of harvested forest products compiled for Kenya to date. This diversity is broadly consistent with the pattern reported for other East African and Horn of Africa dry Afromontane systems, where household NTFP collection likewise spans a wide range of plant families and use categories [20, 21]. The dominance of medicinal plants in both species richness and economic value mirrors findings from other East African highland forests [29, 30] and from urban herbal markets elsewhere in the region [33], reflecting both the depth of Kenya's ethnobotanical heritage and a wider regional trend of intensifying commercialization of traditional medicine. Our finding that eight of the ten highest-use-value species occur predominantly at the forest edge or in the understory is consistent with evidence from southern African and South American NTFP value chains showing that edge and boundary zones are disproportionately important for livelihoods yet disproportionately vulnerable to land-use conversion [22, 32]. Forest management strategies that treat the edge zone as a sacrificial buffer rather than a critical resource zone are therefore likely to undermine both biodiversity and livelihood outcomes [7–9].

4.2. NTFPs as a Safety Net: Poverty and Gender Policy Implications.

NTFPs contributed approximately 28.4% of household income overall, rising to over 40% among the poorest quintile and female-headed households. This safety-net pattern is consistent with evidence from other African NTFP-dependent economies, including landscape-restoration contexts in Niger [2] and NTFP-based livelihood strategies in South Asian mountain systems [3], suggesting that the function documented here reflects a broader structural role of NTFPs in agrarian, forest-adjacent economies rather than a phenomenon unique to Kenya. The counter-cyclical temporal pattern of NTFP income relative to agricultural income confirms that NTFPs perform a smoothing function that is qualitatively distinct from, and difficult to substitute with, other income sources in the short term. These findings challenge policy narratives that frame NTFP dependence primarily as a symptom of poverty to be resolved through agricultural intensification; deliberate support for NTFP value chains may instead be a more effective pathway to sustainable income growth for the most vulnerable households [31, 32]. The gender dimensions of NTFP dependence documented here reinforce feminist political ecology scholarship [27, 28]: women's higher reliance on NTFPs, combined with their systematic exclusion from CFA governance (31.4% of membership, 14.2% of leadership), creates a double vulnerability in which women bear the greatest livelihood risk from NTFP depletion while holding the least institutional power to prevent it. Comparable governance exclusion of women NTFP harvesters has been documented in Somaliland and Tanzania [29, 30], suggesting this is a regional institutional pattern rather than one unique to Kenya's CFAs. Addressing it requires enforcing the gender quotas already stipulated, but rarely applied, under the FCMA, and deliberately incorporating women's NTFP knowledge into species prioritization, harvest rule design, and monitoring: a priority for Kenya's National Gender and Equality Commission, working with KFS and the Ministry of Environment [5, 6, 8, 9, 27].

4.3. Harvest Sustainability, Commercial Pressure, and Limitations of the HPI.

The finding that 76.7% of assessed species face moderate-to-critical harvest pressure is a significant conservation concern, particularly given that 11 species are harvested above estimated sustainable yield. The dominant driver of critical pressure is commercialization of high-value medicinal species for urban and export markets, a pattern also documented elsewhere in East Africa and in tropical forest systems globally [33, 34]. Prunus africana, the most critically overexploited species in our assessment, is listed on CITES Appendix II, yet our data indicate that a substantial volume of bark is harvested outside the regulated trade system [35]. Strengthening the forest-to-market chain of custody for high-value medicinal NTFPs will require coordinated action between KFS, the Kenya Plant Health Inspectorate Service (KEPHIS), and county market authorities. The HPI performed well as a practical, transparent sustainability screening tool that integrates household harvest data with plot-based productivity estimates, and we recommend its adoption as a standard indicator within CFA management plan annual reviews. However, three limitations of the HPI as applied here warrant caution in interpreting the sustainability results. First, sustainable yield estimates for several species relied on productivity values from the literature rather than site-specific data, introducing uncertainty that is likely largest for species with the least local research history; HPI values for these species should be treated as indicative rather than precise. Second, the HPI is a landscape-level average that can mask spatial heterogeneity in harvest pressure, a species classified as moderate pressure overall may nonetheless be under critical, spatially concentrated pressure near specific access points or markets, consistent with our accessibility regression result ($\beta = 0.44$). Third, the HPI as calculated here does not incorporate inter-annual or climate-related variation in productivity (e.g., drought-driven flowering failure), so single-period HPI estimates may not capture year-to-year variability in sustainable yield. These limitations mean that HPI values should inform, rather than substitute for, site-level regeneration monitoring: our finding that 7 of the 11 critical-pressure species also showed inadequate natural regeneration provides independent corroboration of the HPI-based classification for those species, and this convergence is what we recommend practitioners rely on most heavily when prioritizing intervention. Future application of the HPI in Kenya would benefit from multi-year monitoring and locally derived productivity data for the highest-value medicinal species [5, 6, 32].

4.4. CFA Governance and Sustainable NTFP Management.

The positive association between CFA membership and sustainable harvest practice adoption (OR = 2.87) is one of the most policy-relevant findings of this study: it provides Kenya's first quantitative evidence that PFM institutions translate into measurable behavioral change in

NTFP management, consistent with cross-tropical meta-analytic evidence that adequately empowered community institutions can match state-managed conservation outcomes at lower cost. The qualitative data identify the specific mechanisms, rule-making, monitoring and sanctioning, and benefit-sharing, through which CFAs generate this effect, offering forest managers a practical basis for targeting CFA capacity-building at the specific mechanism a given CFA is weakest in, rather than pursuing generic institutional strengthening [9, 27, 32]. At the same time, our data reveal implementation gaps that limit PFM's effectiveness as an NTFP governance instrument in practice. Only 22 of 34 CFAs had NTFP-specific provisions in their management plans, despite this being a formal KFS requirement, a shortfall likely explained by limited technical capacity among CFA officials, constrained KFS extension support, and the historical marginalization of NTFPs relative to timber in forest management planning culture. For forest managers and conservation planners, the most immediately actionable response is a low-cost, high-impact retrofit: inserting KEFRI-developed, species-specific harvest guidelines into existing management plans, rather than waiting for a full management-plan revision cycle, would close this gap fastest [6–9, 32].

4.5. Policy Implications.

Drawing together the evidence above, four priority actions emerge for Kenya's forest and land governance policy. First, the FCMA's PFM provisions should be strengthened through a dedicated NTFP management regulation setting minimum standards for species coverage, harvest rule specificity, and enforceable (not merely stipulated) gender-inclusive governance in CFA management plans, building on the retrofit approach. Second, Kenya's green economy strategy should treat NTFP value chains, particularly medicinal plants, not as a supplementary rural income activity but as a primary livelihood support mechanism for forest-adjacent women and low-income households, with dedicated funding for product quality certification and market linkage. Third, CITES-regulated species, above all Prunus africana, require an emergency national action plan addressing both formal trade regulation and the informal harvest identified in this study as driving the most critical stock depletion. Fourth, Payment for Ecosystem Services (PES) mechanisms under Kenya's NDC implementation framework should explicitly value NTFP provisioning services alongside carbon and hydrological services, enabling communities to capture additional value from sustainable forest management. Collectively, these four measures translate the diversity, livelihood, and governance evidence presented in this study into a coherent, actionable policy package for community forest management and conservation planning, rather than a set of isolated recommendations [7, 12, 13, 37].

5. Conclusions

This study provides multi-method evidence that NTFPs make a substantial, safety-net-critical contribution to the livelihoods of forest-adjacent communities in two major Kenyan forest landscapes, with particular significance for women and the poorest households. The 94 NTFP species documented, together with the household income analysis and harvest sustainability assessment, constitute the most detailed empirical baseline available for NTFP management in Kenya's montane forests. That more than three-quarters of assessed commercially important species face moderate-to-critical harvest pressure, driven primarily by commercial demand for medicinal plants, signals an urgent need for governance intervention. Community Forest

Associations, empowered under the 2016 FCMA, are the most promising institutional vehicle for this intervention, as shown by the strong positive association between CFA membership and sustainable harvest practice adoption. Realizing this potential, however, requires the targeted reforms identified above: mandatory NTFP provisions in management plans, enforceable gender-equitable governance, and stronger KFS extension support. Without these reforms, and without urgent action on the most critically overexploited species, Kenya risks undermining both the biodiversity of its highland forests and the livelihood security of its most forest-dependent communities. As Kenya implements its NDC commitments, develops its green economy strategy, and refines community land governance, the evidence presented here makes a clear case for treating NTFPs as a central pillar of integrated forest–livelihood policy rather than a peripheral forest management concern.

Author Contributions

All authors contributed equally to this work.

Competing Interests

The authors declare no competing interests.

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