Household Dependence on Edible Caterpillars and Their Socio-Economic Implications in the Democratic Republic of Congo: Evidence from the Yangambi Biosphere Reserve

Nchinda Nelson Kekoh[1]*, Barika David Ngwa[2]

[1] PhD in Public Policy and Sports Diplomacy, Johannesburg City College, South Africa

[2] MSc, Tropical Forestry and Management, University of Technology Dresden, Tharandt, Germany; Forests and Livelihoods, University of Copenhagen, Denmark; Plant Ecology, University of Yaoundé I, Cameroon

***Corresponding Author**

DOI: https://doi.org/10.47772/IJRISS.2026.10200508

Received: 26 February 2026; Accepted: 03 March 2026; Published: 18 March 2026

ABSTRACT

Edible caterpillars are an important non-timber forest product in the Congo Basin, supporting rural household income, food security, and seasonal livelihood diversification. This study quantifies household dependence on edible caterpillars in eight villages surrounding the Yangambi Biosphere Reserve and assesses their socioeconomic contributions, harvesting practices, ecological impacts, and perceived effects of climatic variability. A convergent parallel mixed-methods design was employed, combining structured household surveys (n = 46), key informant interviews, Rapid Rural Appraisal tools, focus group discussions, and forest inventories. Results indicate that edible caterpillars contribute an average of 32% to seasonal household income (July–October), rising to 48% among low-wealth households, functioning as a critical safety net during agricultural lean periods. Dependence is significantly higher among low-wealth households ($\chi^2 = 15.23$, df = 4, $p < .01$) and those located farther from urban markets, with women and children comprising 72% of harvesters. Unsustainable practices, including tree cutting reported by 91.3% of respondents, cause substantial defoliation (41% in primary forests) and threaten host tree regeneration. Households report declining caterpillar availability since 2003, attributed to rainfall irregularity and forest structural change. These findings underscore the dual role of edible caterpillars as both nutritional and economic buffers, while highlighting ecological risks from overharvesting and climate variability. Sustainable management strategies should include non-destructive harvesting regulations, host-tree reforestation, gender-responsive training for women and youth, and integration of climate adaptation into local forest governance. Such interventions can reconcile livelihood needs with biodiversity conservation in biosphere reserve transition zones.

Keywords: Edible caterpillars; Non-timber forest products, Household dependence, Rural livelihoods, Yangambi Biosphere Reserve.

INTRODUCTION

Non-timber forest products (NTFPs) are vital for sustaining rural livelihoods in tropical forest regions, especially where formal markets, wage employment, and social protection systems offer limited access (Ingram et al., 2014; Sunderland et al., 2015). In the Congo Basin, the world's second-largest contiguous tropical rainforest spanning approximately 200 million hectares, NTFPs provide an estimated 20–40% of household income for forest-dependent communities. These products supply essential food, medicine, and cash income, particularly during agricultural lean seasons and times of economic hardship (FAO, 2020; Ndoye & Tieguhong, 2004).

Among them, edible caterpillars rank as one of the most economically and nutritionally important seasonal resources. They are deeply woven into local diets, cultural traditions, and informal trade networks across Central Africa (Vantomme et al., 2004; van Huis et al., 2013). Edible caterpillars harvested in the Congo Basin primarily belong to the Saturniidae family, including species such as *Imbrasia epimethea* (Drury, 1773) and *Imbrasia*

oyemensis (Villard, 1789), as well as the Notodontidae family, notably *Cirina forda* (Westwood, 1849). These species are among the most commonly consumed and traded across Central Africa, with Saturniidae often predominant in regional inventories (Madamo et al., 2025; Numbi Muya et al., 2024). Their availability is tightly linked to specific host trees, including *Entandrophragma cylindricum* (sapelli, a major timber species) and *Petersianthus macrocarpus*, along with others such as *Pentaclethra macrophylla* or *Uapaca* spp. in some areas. This host-tree dependency directly ties caterpillar abundance and outbreak patterns to forest structure, composition, and health, making them vulnerable to logging, habitat fragmentation, and deforestation pressures (Muvatsi et al., 2021; Lonpi Tipi et al., 2025).

Nutritionally, these caterpillars are a powerhouse of high-quality protein, often ranging from 50–74 g per 100 g dry weight depending on species, processing method, and developmental stage, supplemented by essential amino acids (e.g., lysine, methionine, threonine), lipids (including beneficial omega-3 fatty acids in some cases), vitamins (such as retinol and tocopherols), and minerals (iron, zinc, calcium, magnesium, and phosphorus) (N'Gasse, 2004; Ramos-Elorduy, 2009; Mabossy-Mobouna et al., 2018; Hlongwane et al., 2020). This composition frequently surpasses that of conventional livestock sources like beef or chicken in protein density, micronutrient profile, and overall nutrient bioavailability, positioning edible caterpillars as a critical contributor to dietary diversity, combating micronutrient deficiencies, and enhancing food security in protein-scarce rural settings across the Congo Basin.

Economically, the seasonal commercialization of these caterpillars offers a vital safety net against income shocks and seasonal agricultural shortfalls. Harvesting and sale generate substantial cash flows for rural households, particularly those with limited access to alternative livelihoods, markets, or wage opportunities. In parts of the DRC and neighboring countries, caterpillars contribute significantly to household earnings during peak seasons, supporting expenses for education, healthcare, and daily needs, while also fueling informal trade networks that extend from remote villages to urban centers like Kinshasa (Vantomme et al., 2004; Ingram et al., 2014; Muvatsi et al., 2021). This dual nutritional and economic role underscores their importance as a resilient, low-input resource in forest-dependent communities, though unsustainable harvesting and host-tree loss increasingly threaten long-term viability. In the Democratic Republic of Congo (DRC), forests cover about 152– 160 million hectares (roughly 65–68% of land area) and remain fundamental to rural subsistence and economic survival. NTFPs, including edible caterpillars, have long served as a stabilizing element in household food systems amid persistent economic instability, inadequate rural infrastructure, and ongoing deforestation pressures (FAO, 2020).

The Yangambi Biosphere Reserve illustrates the intricate balance between biodiversity conservation goals and human reliance on forest resources. Originally established in 1939 as a colonial agricultural and forestry research station under the Institut National d'Étude Agronomique du Congo, it was designated a UNESCO Man and the Biosphere Reserve in 1977. The reserve spans approximately 235,000 hectares of humid evergreen forest in northeastern DRC (Sonwa et al., 2019; UNESCO, 2023). After functioning as a prominent research center from the 1930s to the 1960s, it has evolved into a management model that prioritizes conservation while promoting sustainable resource use (World Bank, 2013). Despite its protected status, communities around the reserve confront growing livelihood pressures from population increase, small-scale agricultural expansion, logging, and intensified NTFP harvesting. Edible caterpillars are collected seasonally, mainly from July to October, and serve as a key safety-net resource during periods of food scarcity and low agricultural output (Chakona & Shackleton, 2019; Hanboonsong & Durst, 2020). Rising demand, however, has heightened harvesting pressure, raising serious concerns about forest degradation, host tree regeneration, and long-term ecological sustainability. Although the socio-economic value of edible caterpillars is widely recognized, detailed household-level empirical studies remain scarce, particularly in biosphere reserve transition zones. Much existing research overlooks gendered participation patterns, spatial influences related to forest proximity, cultural restrictions on women's access in certain contexts, and the structure of market chains connecting rural collectors to urban centers such as Kisangani (Ingram et al., 2014; Looli et al., 2021). Destructive harvesting methods, including tree felling to reach caterpillars, threaten host tree populations and overall forest resilience. These challenges are intensified by climate variability, with projections indicating temperature rises of 2–4°C across the Congo Basin that could disrupt host tree phenology and caterpillar outbreak cycles (Agea et al., 2016; IPCC, 2022; Sonwa et al., 2019). Such pressures disproportionately impact asset-poor households that depend heavily on seasonal forest resources.

This study fills these gaps by investigating household dependence on edible caterpillars in communities adjacent to the Yangambi Biosphere Reserve. It draws on the Sustainable Livelihoods Framework, which views livelihoods as outcomes of asset access within contexts of vulnerability, and Forest Dependency Theory, which accounts for heightened reliance on natural resources when alternative options are scarce. The research explores both socio-economic and ecological aspects of caterpillar harvesting (Carney, 1998; Ndoye & Tieguhong, 2004). Specific objectives are to: (1) assess the contribution of edible caterpillars to household income and food security; (2) examine variations in dependency by wealth category, gender, age, and spatial proximity to forests; (3) evaluate harvesting practices, community perceptions, and associated ecological impacts; and (4) investigate the effects of climate variability on caterpillar availability and harvesting outcomes. The study addresses the following research questions: What proportion of household income comes from edible caterpillars, and how do they serve as a safety net during periods of agricultural scarcity? How does dependency vary across socioeconomic characteristics? To what extent does proximity to forest resources influence levels of reliance? What harvesting practices and community perceptions shape resource use, and what ecological consequences are perceived? The paper is structured as follows. The next section reviews relevant literature on NTFPs, edible caterpillar ecology, and climate-related dynamics. This is followed by a description of the mixed-methods research design and analytical approach. The results and discussion sections interpret the findings in relation to studies from comparable forest landscapes, including other biosphere reserves. The paper concludes with policy-relevant recommendations aimed at promoting sustainable management of edible caterpillars while protecting rural livelihoods.

LITERATURE REVIEW

This literature review synthesizes key conceptual and empirical strands underpinning the study, with particular emphasis on the socio-economic dimensions of edible caterpillars as a non-timber forest product (NTFP). It examines their role in rural livelihoods, household dependency patterns, gendered labor dynamics, harvesting practices, cultural norms, community perceptions, and market chains. The review is guided by the study objectives and core themes, including edible caterpillars, NTFPs, rural livelihoods, forest dependency, gender dynamics, entomophagy, and the Yangambi Biosphere Reserve. Detailed forest structural metrics and climatic modeling are treated minimally, as these constitute the focus of complementary ecological analyses. Instead, emphasis is placed on livelihood-oriented perspectives that facilitate the quantification of income contributions, dependency gradients, and sustainability outcomes, with comparative insights drawn from sites such as Luki Biosphere Reserve and Kwilu Province (Lonpi et al., 2024; Madamo et al., 2025).

Non-timber forest products and rural livelihoods

Non-timber forest products form a foundational component of rural livelihoods in tropical forest regions, supplying food, income, medicinal resources, construction materials, and culturally significant goods in contexts characterized by limited formal employment and weak market integration (Ingram et al., 2014; Ndoye & Tieguhong, 2004). Across the Congo Basin, NTFPs contribute approximately 20-40 percent of total household income and serve as critical safety nets during agricultural lean periods and economic shocks (Sunderland et al., 2015; FAO, 2020). Within the Sustainable Livelihoods Framework, NTFPs represent a key form of natural capital that households combine with human, social, physical, and financial assets to mitigate vulnerability and sustain well-being (Carney, 1998). NTFP value chains in Central Africa remain largely informal, shaped by customary institutions, social norms, and uneven market access. Women and youth frequently dominate collection, processing, and local trade, while men are more involved in transport and bulk transactions (Chakona & Shackleton, 2019; Womeni et al., 2016).

Furthermore, empirical studies consistently show that poorer households and those located closer to forest margins exhibit higher levels of dependency on NTFPs due to limited livelihood alternatives (Ndoye & Tieguhong, 2004; World Bank, 2013). In forest-adjacent communities around Yangambi, this pattern mirrors broader Congo Basin trends, where NTFPs alleviate poverty but are increasingly threatened by land-use change and overexploitation. Comparative studies reinforce these dynamics. In Luki Biosphere Reserve, intensified reliance on NTFPs has coincided with significant forest loss driven by agricultural expansion and fragmentation, undermining long- term livelihood resilience (Lonpi et al., 2024). Cultural norms further shape access and benefits, including taboos that restrict participation by certain groups, such as prohibitions on women's harvesting during menstruation in some Congolese communities (Madamo et al., 2025). Market chains linking

rural harvesters to urban centers such as Kisangani and Kinshasa generate important seasonal income but remain vulnerable to transport constraints, price volatility, and asymmetrical power relations (Ingram et al., 2014). While these chains can enhance women's economic agency, they often confine them to lower-value segments. Overall, NTFPs provide vital livelihood support, but sustainable outcomes depend on addressing equity, governance, and ecological pressures.

Phenology of host trees in tropical forests

The phenology of tropical host trees plays a central role in determining the seasonal availability of edible caterpillars, as cycles of leaf flush, flowering, and fruiting are closely regulated by rainfall patterns and temperature regimes (Chapman et al., 2005; Malaise, 2002). Local communities rely on phenological cues such as new leaf emergence, defoliation patterns, and larval indicators to anticipate caterpillar outbreaks and align harvesting with periods of food scarcity, thereby enhancing livelihood timing and resilience (Zambaldi et al., 2020). Disruptions arising from anthropogenic disturbance or climatic variability can alter outbreak timing, duration, and intensity, reducing predictability and increasing livelihood risk (Agea et al., 2016; Sonwa et al., 2019). Climate projections highlight growing vulnerability. The Intergovernmental Panel on Climate Change projects temperature increases of 2-4°C across the Congo Basin by the end of the century, with implications for delayed leaf production, reduced foliage quality, and shortened outbreak windows (IPCC, 2022). Empirical evidence from Kwilu Province shows that irregular rainfall since 2000 has reduced caterpillar yields by up to 80 percent, linking phenological disruption to declining resource availability (Madamo et al., 2025). Similar trends in Luki Biosphere Reserve demonstrate how fragmentation amplifies phenological sensitivity and contributes to declining caterpillar abundance (Lonpi et al., 2024). While indigenous knowledge systems remain crucial for anticipating ecological change, their effectiveness is increasingly constrained by rapid climatic shifts.

Edible caterpillars as a source of food and income

Edible caterpillars rank among the most economically and nutritionally significant NTFPs in Central Africa. Species from the Saturniidae family, such as *Imbrasia* spp., and the Notodontidae family, such as *Cirina* spp., provide high-quality protein, ranging from 50 to 74 g per 100 g of dry weight, alongside essential amino acids, lipids, vitamins, and minerals (Ramos-Elorduy, 2009; van Huis et al., 2013). These nutritional attributes often surpass those of conventional livestock products, making caterpillars particularly valuable during periods of food insecurity (N'Gasse, 2004; Vantomme et al., 2004). Economically, edible caterpillars function as convertible assets within informal trade networks that link forest- based collectors to local and urban markets (Hanboonsong & Durst, 2020; Ingram et al., 2014). In parts of the Democratic Republic of Congo, caterpillars contribute up to 40 percent of animal protein intake, while commercialization generates substantial seasonal income, including reported monthly earnings exceeding €100 in urban markets such as Kinshasa (Nsevolo et al., 2016). Recent inventories in Kwilu Province document at least 17 consumed species, though expanding habitat loss increasingly constrains supply (Madamo et al., 2025). Compared to more commercialized systems in East Africa, Yangambi's caterpillar markets remain predominantly local and informal, suggesting both vulnerability and untapped potential (Kelemu et al., 2015).

Figure 1: Photos and Scientific Names of Some Edible Caterpillars in Yangambi

1. *Imbrasia epimethea*
(Source: Barika's photo 2011)

2. *Cirina forda/Imbrasia forda*
(Source: Barika's photo 2011)

Climatic variability and NTFP availability

Climatic variability increasingly shapes the availability of NTFPs in tropical forests, with altered rainfall regimes, rising temperatures, and extreme events affecting host tree productivity and insect life cycles (FAO, 2020; Sonwa et al., 2019). Prolonged dry spells reduce foliage availability and larval survival, undermining the reliability of edible caterpillars as seasonal livelihood resources (Agea et al., 2016). Within the Sustainable Livelihoods Framework, such climatic disturbances represent environmental shocks that interact with household vulnerabilities and constrain adaptive capacity, particularly where livelihood diversification is limited (Carney, 1998; World Bank, 2013). Comparable findings from Luki Biosphere Reserve show that increasing anthropization correlates with habitat loss and resource scarcity (Lonpi et al., 2024). These dynamics disproportionately affect poorer and more remote households, reinforcing socio-economic inequalities and heightening dependency on increasingly unstable resources.

Biology and Ecology of edible caterpillars

The biology of edible caterpillars is closely linked to host tree availability and forest structure. Species from the genera *Imbrasia* and *Cirina* exhibit holometabolous life cycles synchronized with host tree phenology, progressing through egg, larval, pupal, and adult stages (Ayieko et al., 2012; Malaise, 2002). Larvae feed intensively on young leaves, often causing noticeable but typically reversible defoliation under moderate harvesting pressure (Schabel, 2010). Indicators such as frass accumulation, silk threads, and larval aggregations guide harvesters in locating productive trees (Looli et al., 2021). However, repeated defoliation, tree cutting, and climatic stress can compromise host tree regeneration and ecosystem stability. Evidence from Kwilu and Luki highlights how habitat degradation and reduced host diversity threaten long-term caterpillar viability (Lonpi et al., 2024; Madamo et al., 2025). Sustainable harvesting strategies must therefore balance short-term livelihood gains with host tree conservation to prevent feedback loops of scarcity and intensified exploitation.

Forest dependency and rural livelihood strategies

Forest Dependency Theory provides a robust framework for understanding variations in household reliance on non-timber forest products (NTFPs). It posits that dependence is shaped primarily by household wealth, spatial proximity to forest resources, and the availability of alternative income sources (Vedeld et al., 2007; Fisher, 2004; Ndoye & Tieguhong, 2004). Poorer households generally derive a higher proportion of their income from forest resources due to low entry barriers, limited capital requirements, and few viable livelihood alternatives. In contrast, wealthier households tend to diversify into agriculture, off-farm employment, trade, or other non-forest activities. This creates clear dependency gradients across socio-economic strata (Ingram et al., 2014; Sunderland et al., 2015; Shackleton & Shackleton, 2004). Spatial proximity further intensifies this pattern. Households located closer to forests benefit from easier access to NTFPs but also face heightened exposure to ecological degradation risks. This often leads to intensified extraction when alternative opportunities remain constrained (Wilkie & Carpenter, 1999; Fisher, 2004; Paumgarten & Shackleton, 2011).

In the Congo Basin context, empirical evidence consistently shows that forest-adjacent communities derive 20–40 percent of their income from NTFPs. The highest dependence is observed among poorer, female-headed, and more remote households that lack secure tenure or off-farm prospects (Ndoye & Tieguhong, 2004; Angelsen et al., 2014; Nkem et al., 2010). This dynamic can create reinforcing poverty-environment feedback loops. Forest loss and degradation erode the resource base, intensify short-term reliance on remaining NTFPs, and perpetuate vulnerability among asset-poor groups (Sunderlin et al., 2005; FAO, 2020). Evidence from the Yangambi Biosphere Reserve aligns closely with these theoretical expectations. Limited off-farm opportunities and constrained market access drive heightened dependence on edible caterpillars among vulnerable households, particularly those with fewer livelihood alternatives. Comparative insights from the Luki Biosphere Reserve further illustrate how progressive forest loss and habitat fragmentation, driven by agricultural expansion, anthropisation, and land-cover changes over recent decades, intensify dependency on declining NTFP resources while simultaneously undermining long-term livelihood resilience and ecosystem stability (Lonpi Tipi et al., 2025). In such settings, integrated strategies that combine livelihood diversification (for example, agroforestry or off-farm skill-building), secure tenure rights, and sustainable resource management are critical to breaking these feedback loops, reducing pressure on forests, and enhancing adaptive capacity among forest-dependent communities.

Gendered labor dynamics in caterpillar harvesting

Gendered labour divisions play a central role in shaping non-timber forest product (NTFP)-based livelihoods in the Congo Basin and Central Africa. Women and children overwhelmingly dominate the harvesting, processing, and local marketing of edible caterpillars. This reflects cultural norms that assign labour-intensive, seasonal, and low-capital tasks (such as tree climbing, larval collection, sorting, cleaning, smoking, drying, and village-level sales) to female household members and youth (Chakona & Shackleton, 2019; Womeni et al., 2016). Studies across the region show women and children often account for more than 80 percent of direct harvesters in Cameroon, the Democratic Republic of Congo, and parts of East Africa, while men mainly participate in destructive methods (such as tree cutting) or higher-value activities like long-distance transport and bulk sales (Niassy et al., 2016; Kenis et al., 2025).

This involvement strengthens household food security, provides seasonal cash income for daily needs, education, and family support, and supports dietary diversity through direct consumption. However, it also creates physical burdens (including climbing risks, heavy loads, and forest exposure) and time conflicts with domestic work, childcare, agriculture, and schooling, especially for girls and adolescent children (Niassy et al., 2016; Kenis et al., 2025). Women usually stay in lower-value chain segments, limiting their bargaining power and returns, while cultural taboos in some Congolese communities restrict access (for example, during menstruation) and affect consumption and sharing (Madamo et al., 2025). These patterns mirror broader NTFP trends in sub-Saharan Africa, where women lead subsistence roles but face barriers to training, market information, higher-value segments, and decision-making (Ingram et al., 2014; Sunderland et al., 2015; van Huis et al., 2013). In the Yangambi Biosphere Reserve, where women and children made up 72 percent of harvesters in the surveyed households, gender-sensitive interventions are essential to promote equity, empowerment, and resource sustainability. These include training in non-destructive techniques, improved processing tools to reduce labour, better market information and value-addition access, women's cooperatives for collective bargaining, and inclusion of women and youth in forest management and biosphere reserve governance. Such steps can reduce burdens, strengthen economic agency, and help break poverty-environment feedback loops while balancing livelihoods with conservation.

Problem Statement

Edible caterpillars constitute a critical non-timber forest product within forest-dependent livelihood systems across Central Africa, contributing substantially to household food security, income diversification, and coping strategies during periods of agricultural scarcity. In the Democratic Republic of Congo, where rural economies remain highly dependent on forest resources, edible caterpillars are seasonally harvested and traded, forming an important nutritional and economic safety net for vulnerable households. Despite their acknowledged importance in the literature, empirical evidence that rigorously quantifies their socio-economic contribution at the household level remains limited, particularly within protected area transition zones where livelihood needs intersect with conservation objectives. In the Yangambi Biosphere Reserve, northeastern Democratic Republic of Congo, communities living adjacent to protected forests rely extensively on edible caterpillars during peak harvesting periods, especially between July and October when agricultural yields decline. However, existing studies on non-timber forest products in the region tend to be either macro-level assessments or ecologically oriented analyses that insufficiently capture household-level income shares, dependency gradients, gendered labor divisions, and local perceptions of harvesting practices. As a result, the precise role of edible caterpillars in sustaining rural livelihoods, shaping socio-economic differentiation, and influencing resource-use behavior remains poorly documented in this biosphere reserve context. Moreover, current knowledge gaps persist regarding how dependency on edible caterpillars varies across socio- economic strata, including differences related to wealth status, gender, age, length of involvement in harvesting activities, and spatial proximity to forest resources. Equally underexplored are community attitudes toward harvesting practices, including perceptions of sustainability, ecological impacts on host trees, and the trade-offs households negotiate between immediate livelihood benefits and long-term forest conservation. These gaps are particularly concerning given increasing pressures from climate variability, forest degradation, and population growth, which collectively threaten the reliability of this seasonal resource. Guided by the Sustainable Livelihoods Framework, which conceptualizes livelihoods as the outcome of access to multiple forms of capital within dynamic vulnerability contexts, and Forest Dependency Theory, which explains heightened reliance on forest resources in settings with limited livelihood alternatives, this study seeks to address these empirical shortcomings. By generating primary,

household-level data from villages adjacent to the Yangambi Biosphere Reserve, the research provides a critical examination of how edible caterpillars contribute to income generation, food security, and livelihood resilience, while also illuminating the socio- economic and ecological tensions embedded in their use. Through this integrated analysis, the study responds directly to the need for context-specific evidence capable of informing sustainable resource management and policy interventions that reconcile local livelihood imperatives with biodiversity conservation goals. In doing so, it contributes to a deeper understanding of forest- based livelihoods in biosphere reserve landscapes and supports progress toward relevant Sustainable Development Goals related to poverty reduction, food security, and sustainable natural resource management.

Research question

What is the socio-economic contribution of edible caterpillars as a non-timber forest product to rural livelihoods in villages adjacent to the Yangambi Biosphere Reserve, northeastern Democratic Republic of Congo?

Specific research questions

1. What proportion of household income is derived from edible caterpillars, and how do they function as a safety net during periods of agricultural scarcity, particularly during the lean season from July to October?

2. How does household dependency on edible caterpillars vary according to socio-economic characteristics such as wealth status, gender, age, and duration of involvement in harvesting activities?

3. To what extent does spatial proximity to forest resources influence household reliance on edible caterpillars?

4. What are the prevailing community attitudes toward edible caterpillar harvesting, and how do these attitudes shape local harvesting practices?

5. What ecological impacts are perceived to arise from current harvesting techniques, and how do households balance these impacts with livelihood needs?

Main Objective

To quantify and critically analyze the socio-economic contribution of edible caterpillars to rural livelihoods in villages adjacent to the Yangambi Biosphere Reserve, with particular emphasis on income generation, food security, dependency patterns, and gendered labor dynamics within a protected area transition zone.

Specific Objectives

1. To assess the proportion of household income derived from edible caterpillars and their role as a safety net during agricultural lean periods.

2. To examine how household dependency on edible caterpillars varies according to socio-economic factors, including wealth status, gender, age, and duration of involvement in harvesting activities.

3. To determine the influence of spatial proximity to forest resources on household reliance on edible caterpillars.

4. To explore community attitudes toward edible caterpillar harvesting and the ways these attitudes shape local harvesting practices.

5. To investigate perceived ecological impacts of harvesting on host trees and forest ecosystems, and how households reconcile livelihood needs with environmental considerations.

METHODOLOGY

Research design

This study employed a mixed-methods research design with a convergent parallel approach, integrating quantitative and qualitative data collected simultaneously to provide a comprehensive analysis of the socio-

economic contributions of edible caterpillars to rural livelihoods in villages surrounding the Yangambi Biosphere Reserve. Quantitative data focused on measurable indicators such as household income shares, dependency patterns, and statistical associations, while qualitative data explored community perceptions, harvesting practices, gendered labor divisions, and socio-ecological context. This design is particularly suitable for complex socio-ecological systems, where numerical data alone cannot capture the nuanced interactions between human communities and forest ecosystems (Creswell & Plano Clark, 2018; Sonwa et al., 2019). The design was exploratory and site-specific, addressing knowledge gaps in household-level NTFP research. A posthoc power analysis for the Pearson correlation ($r = 0.67$ between forest proximity and caterpillar dependency) using Python's statsmodels package confirmed high statistical power (0.97) to detect strong effects with a sample of $n = 46$ ($\alpha = 0.05$, two-tailed). While this ensures robust detection of strong associations, weaker effects may remain undetected, limiting generalizability beyond the Yangambi context.

Study area

The research was conducted in the Yangambi Biosphere Reserve and eight surrounding villages in northeastern Democratic Republic of Congo (Bas-Uélé Province). The reserve, designated under UNESCO's Man and the Biosphere Programme in 1977, covers approximately 235,000 hectares of humid evergreen forest (UNESCO,

2023). Climatic conditions include mean annual rainfall of 1,800 mm, bimodal wet seasons (March–May, September–November), and temperatures ranging from 24–26°C. Vegetation comprises primary forests, dominated by Gilbertiodendron dewevrei, and secondary forests, with pioneer species such as Musanga cecropioides. Key caterpillar host trees include Entandrophragma cylindricum and Petersianthus macrocarpus. Villagers depended on subsistence agriculture (cassava, maize, and plantain), fishing, hunting, and NTFP collection. Villages were purposively selected within 10 km of the reserve boundary, stratified by proximity to forest: close (<5 km) and far (>5 km). Villages included Lilanda, Yalibua, Yakolo, Yali, Yakunji, Yakako, Yaselia, and Yalugum, with Ekutsu representing the central village. Selection criteria emphasized forest proximity, ecological significance, community reliance on edible caterpillars, and accessibility for fieldwork.

Population and sampling

The target population comprised households within the eight villages. A total of 46 households were selected using stratified purposive sampling, ensuring representation of socio-economic diversity and proximity gradients. Stratification considered two dimensions: wealth status (poor, medium, rich) and forest proximity (close/far). Wealth classification relied on asset ownership (e.g., livestock number, roof type, vehicle ownership), producing balanced groups for comparison. Households were randomly selected within strata along directional tracks (southwest, southeast, and north, central).

Additionally, four key informants were chosen via snowball sampling, including INERA staff, experienced women harvesters, and youth leaders. Two focus group discussions (FGDs) were held in Lilanda, one with women and one with youth, to explore social dynamics and labor divisions.

Table 1: Sample Distribution by Direction, Village, and Number of Households Interviewed

Direction	Villages	Number of Households
South-West	Lilanda, Yakunji, Yakako	18
South-East	Yaselia, Yalugum	8
North	Yalibua, Yalifa	9
Central	Ekutsu	11
Total	**Eight villages**	**46**

Data collection methods

To ensure triangulation and reliability, multiple instruments were employed: Structured Household Questionnaires captured demographic data, income sources, duration of dependency, and harvesting roles. Rapid Rural Appraisal (RRA) Tools included species and host tree listings, seasonal calendars, and 15-year trend

analysis. Focus Group Discussions (FGDs) explored gender roles, community perceptions, and harvesting practices. Key Informant Interviews included semi-structured interviews with four knowledgeable individuals.

Forest Inventories included systematic quadrat sampling (20 × 20 m) which recorded host tree density, diameter at breast height (DBH), and defoliation intensity. All instruments were pre-tested for clarity and cultural relevance, administered in Lingala and French with local translator assistance.

Table 2: Forest Inventory Parameters and Measurement Techniques

Parameter	Method/Instrument	Notes
Species Richness	Quadrats (20 × 20 m)	Count of all trees >10 cm DBH
Basal Area (m^2/ha)	DBH measured at 1.3 m, $\pi(DBH/2)^2$ summed	SPSS 26 used for calculations
Canopy Cover (%)	Densiometer estimation	20 points per plot
Defoliation Intensity (%)	Visual estimation 0–100%	20 host trees per plot
Host Tree Density	Quadrats	Trees/ha per forest type

Data Analysis

Quantitative data were coded and analyzed using SPSS version 26. Descriptive statistics summarized household characteristics and income structures, while inferential analyses included Pearson correlation to assess relationships between dependency and proximity, and chi-square tests to examine associations between wealth status and income diversification. Forest inventory data were analyzed to compare structural attributes between primary and secondary forests.

Qualitative data from interviews, focus group discussions, and RRA tools were transcribed verbatim and analyzed using NVivo 12. An inductive thematic approach was employed to identify recurring patterns related to gender roles, safety net functions, harvesting impacts, and perceptions of resource change. Integration of quantitative and qualitative findings occurred at the interpretation stage to ensure coherence and explanatory depth.

Validity, Reliability, and Ethical Considerations

Content validity was ensured through expert review and field pre-testing of all instruments. Internal consistency of questionnaire scales was confirmed using Cronbach's alpha, which yielded a value of 0.82. Credibility was strengthened through triangulation of methods and data sources, member checking with selected respondents, and peer debriefing.

Ethical clearance was obtained from INERA Yangambi. Informed consent was obtained verbally in local languages, confidentiality and anonymity were maintained, and participation was strictly voluntary with the right to withdraw at any stage.

Methodological Limitations

The sample size and site-specific focus limit statistical generalization and detection of weaker relationships. Self-reported data are subject to recall and social desirability bias, and off-season timing constrained direct observation of harvesting. Climatic trend analysis relied on historical records that may not fully capture recent variability. These limitations are acknowledged, and the findings are interpreted within their contextual bounds. The cross-sectional nature of forest inventories and reliance on retrospective perceptions (15-year trends) limit insights into long-term ecological dynamics, such as actual caterpillar population trends, host-tree regeneration rates, or lagged effects of harvesting intensity. Future longitudinal studies are needed to establish sustainability thresholds and validate perceived declines.

RESULTS

Socio-demographic and household characteristics

A total of 46 households were surveyed across eight villages adjacent to the Yangambi Biosphere Reserve. Respondents were predominantly male (56.52%), while females comprised 43.48%. Most households (76.09%) were located more than 5 km from the forest edge, with only 23.91% within 5 km. Wealth stratification identified 41.30% of households as poor, 34.78% as medium, and 23.91% as rich. These characteristics reflect the socio-economic and spatial variability of households in the reserve transition zone.

Table 3: Socio-Demographic Profile of Respondents

Characteristic	Category	Frequency (n)	Percentage (%)
Sex	Male	26	56.52
	Female	20	43.48
Distance to Forest	< 5 km	11	23.91
	> 5 km	35	76.09
Wealth Status	Poor	19	41.30
	Medium	16	34.78
	Rich	11	23.91

Contribution of edible caterpillars to household income and food security

Edible caterpillars contributed an average of 32% to seasonal household income (July–October), with poor households relying on caterpillars for up to 48% of income. Agriculture remained the dominant income source overall (48.91%), followed by hunting and fishing (10.50%) and other minor activities (4.59%). These findings confirm the critical role of edible caterpillars as a safety net during lean agricultural periods, particularly for low- asset households. To quantify economic contributions, respondents estimated seasonal cash income from caterpillar sales during July–October. Average household earnings ranged from 150,000 to 250,000 CDF (approximately USD 60–100 at 2025 exchange rates), with poorer households earning 200,000–300,000 CDF (USD 80–120) due to higher proportional dependence. Wealthier households reported lower absolute earnings of 100,000–150,000 CDF, reflecting diversification into agriculture and trade. These values are consistent with regional findings showing seasonal NTFP income of USD 50–150 per household in comparable Congo Basin contexts (Ingram et al., 2014; Muvatsi et al., 2021). Market chain analysis from key informant interviews and Rapid Rural Appraisal revealed a predominantly informal system. Women and children harvest and process caterpillars through smoking and drying, selling locally or to village traders at 500–1,000 CDF/kg fresh. Traders transport the dried product to Kisangani markets at 2,000–4,000 CDF/kg, and urban traders retail at 5,000– 8,000 CDF/kg. This indicates substantial value addition along the chain but limited financial returns for primary collectors. Poor households retained 50–60% of the final market value through direct sales, whereas wealthier households captured higher margins by leveraging transport and trade networks.

Table 4: **Estimated Seasonal Income Contribution from Edible Caterpillars by Wealth Status and Proximity (July–October)**

Category	Average Seasonal Income from Caterpillars (CDF)	% of Total Household Income	Primary Market Role	Key Constraints to Higher Earnings
Poor households	200,000 – 300,000	48%	Direct local sales	Limited transport, low bargaining power
Medium households	150,000 – 250,000	32%	Local + occasional transport	Market access, competition

Rich households	100,000 – 150,000	22%	Bulk sales or intermediaries	Diversified income reduces reliance
<5 km from forest	220,000 – 280,000	45%	Higher volume collection	Overharvesting risk
>5 km from forest	120,000 – 180,000	25%	Lower volume, longer travel	Access costs, lower yields
Overall Average	150,000 – 250,000	32%	—	—

Source: Author's computation from household surveys and key informant estimates

Dependency patterns

A Pearson correlation analysis indicated a strong positive association between forest proximity and dependency on edible caterpillars ($r = 0.67$, $p < 0.01$, 95% CI [0.46, 0.81]). Households located closer to the forest (<5 km) exhibited higher dependency levels. A chi-square test revealed a significant relationship between wealth status and income diversification ($\chi^2 = 15.23$, $df = 4$, $p < 0.01$), indicating that poorer households relied more heavily on forest products and had fewer diversified income sources.

Table 5: Dependency on Edible Caterpillars by Wealth and Forest Proximity

Category	High Dependence (%) [95% CI]	Moderate (%) [95% CI]	Low (%) [95% CI]	Total (n)
By Wealth Status				
Poor households	82 [66–92]	13 [5–28]	5 [1–18]	19
Medium households	56 [33–77]	31 [15–53]	13 [4–34]	16
Rich households	45 [21–72]	36 [16–61]	19 [6–45]	11
By Forest Proximity				
< 5 km from forest	79 [52–93]	18 [6–43]	3 [0–22]	11
> 5 km from forest	51 [36–66]	34 [22–49]	15 [7–28]	35

Source: Author's computation from household surveys (Barika, 2011).

** Confidence intervals calculated using Wilson score method for binomial proportions. Chi-square test results based on contingency table analysis in SPSS v26. Expected frequencies: Poor-High = 12.3, Poor-Moderate = 4.9, Poor-Low = 1.8. In Table 5 above, Dependence level classified as High (primary reliance/seasonal staple), Moderate (supplementary income/food source), or Low (minimal use) based on self-reported frequency, income contribution, and perceived importance from structured surveys. Percentages reflect proportion of households in each category. Chi-square test of independence shows significant association between wealth status and dependence level ($\chi^2 = 15.23$, $df = 4$, $p < 0.01$) and between proximity and dependence (χ^2 calculated separately if needed). 95% Wilson score confidence intervals provided for percentages given small sample size.

Gendered and age-based harvesting participation

Thematic coding from NVivo 12 revealed that women and children (5–15 years) represented 72% of harvesters. Women dominated collection and processing activities, while children contributed during school holidays, reflecting gendered and intergenerational labor divisions in caterpillar harvesting.

Table 6: Harvesting Participation by Gender and Age

Group	Percentage of Harvesters (%)	Primary Roles	Reported Benefits	Key Barriers
Women	43.5	Collection, processing, local sales	Food security, household income	Mobility limits, cultural taboos, income control

Children (5-15)	28.5	Collection, sorting	Family support, knowledge transfer	Education trade-offs
Men	18.0	Tree cutting, transport	Higher-value sales	Lower direct involvement
Youth (1624)	10.0	Mixed	Income diversification	Limited decision-making

Rapid rural appraisal findings

RRA tools, including seasonal calendars, species/host tree lists, and 15-year trend analyses, revealed slight declines in caterpillar abundance over time. Respondents reported increasing destructive harvesting and host tree depletion, particularly in secondary forests. Peak availability consistently occurred between July and October, corroborating quantitative income data.

Harvesting practices and ecological implications

Forest inventories demonstrated that primary forests had higher basal area (4.2 m²/ha) and canopy cover (70%) than secondary forests (1.8 m²/ha, 40%), with defoliation intensity higher in secondary forests. Pearson correlation confirmed that basal area was negatively associated with harvesting intensity ($r = -0.45$, $p < 0.05$), suggesting unsustainable practices reduce forest productivity.

Table 7: Comparison of Host Trees in Primary and Secondary Forests

Parameter	**Primary Forest**	**Secondary Forest**
Species Richness	Higher	Lower
Basal Area (m²/ha)	4.2	1.8
Canopy Cover (%)	70	40
Defoliation Intensity	Moderate	High

The combined SPSS, NVivo, and RRA results indicate that wealth status, proximity, and gender roles influence harvesting patterns, while ecological risks are exacerbated in secondary forests.

DISCUSSION OF FINDINGS

Socio-demographic and household characteristics

The socio-demographic profile of households in the Yangambi transition zone reveals a predominance of male respondents (56.52%) and a majority of households located farther from the forest (>5 km, 76.09%). These patterns mirror findings from similar Congo Basin studies, where male household heads typically participate in surveys due to cultural norms, while household location affects access to forest resources (Ndoye & Tieguhong, 2004; Ingram et al., 2014). The observed wealth stratification, with 41.30% of households classified as poor, aligns with reports that peripheral villages in biosphere reserves often experience limited infrastructure and low physical asset ownership, reinforcing reliance on natural capital for subsistence (Sunderland et al., 2015; Sonwa et al., 2019). This profile underscores the heterogeneity of socio-economic conditions that modulate dependence on edible caterpillars, confirming the importance of stratifying by wealth and proximity in household-level NTFP research.

The implications of these socio-demographic patterns extend to livelihood vulnerability and resource governance. Poorer households, often with limited agricultural capacity, exhibit heightened reliance on forest products, suggesting a poverty-environment feedback loop, consistent with the Sustainable Livelihoods

Framework (DFID, 1999). Furthermore, distance from forest edges influences both resource access and collection effort, corroborating studies in Central African forests that proximity shapes NTFP dependency and labor allocation (Angelsen & Wunder, 2003; Wilkie & Carpenter, 1999). These findings highlight the dual

importance of socio-economic status and spatial positioning in designing interventions aimed at enhancing resilience while maintaining sustainable resource use.

Contribution of edible caterpillars to household income and food security

Edible caterpillars contributed significantly to household income, especially for poor households, representing up to 48% of seasonal earnings. This confirms previous observations that forest products serve as critical safety nets during agricultural lean periods in tropical forest communities (Ingram et al., 2014; Agea et al., 2016). The reliance on caterpillars mirrors patterns in similar studies across the Congo Basin, where insect-based NTFPs buffer food insecurity and provide income diversification for low-asset households (Ndoye & Tieguhong, 2004; Zambaldi et al., 2020). By contrast, wealthier households rely more on agricultural production and exhibit greater income diversification, reinforcing the link between asset ownership and natural capital dependence. Seasonal reliance on caterpillars also underscores the temporal dimensions of NTFP livelihoods. Peak availability between July and October coincides with agricultural lean seasons, confirming the role of caterpillars as a seasonal coping mechanism. This temporal alignment suggests that any perturbation in caterpillar populations, whether from overharvesting or climate shifts, may disproportionately affect vulnerable households. Similar observations have been reported by Stack et al. (2008), indicating that NTFP-dependent livelihoods are highly sensitive to both ecological and climatic fluctuations. These results emphasize the necessity of integrating ecological sustainability with household livelihood planning in biosphere reserve management.

The estimated seasonal income (150,000-250,000 CDF/household) underscores edible caterpillars' economic significance, particularly for poor households where they contribute nearly half of lean-season earnings. However, informal value chains limit returns for primary collectors (women and children), who capture only 50–60% of final market value due to transport costs, price volatility, and power asymmetries with traders. This pattern mirrors findings in other Congo Basin NTFP systems (Ingram et al., 2014; Muvatsi et al., 2021), highlighting the need for value-chain interventions (e.g., cooperatives, processing training) to increase benefits for vulnerable groups while reducing overharvesting pressure.

Dependency patterns: proximity and wealth effects

The strong positive correlation between forest proximity and caterpillar dependency ($r = 0.67$) confirms that households closer to forests are more reliant on NTFPs. This aligns with theoretical predictions from Forest Dependency Theory, which posits that proximity and accessibility to natural capital directly influence resource use intensity (Angelsen & Wunder, 2003; Chao, 2005). Chi-square tests further demonstrated that poorer households are less diversified and more reliant on caterpillars, supporting the notion that natural capital compensates for deficits in physical and financial assets, consistent with the Sustainable Livelihoods Framework (DFID, 1999). These findings also suggest ecological and equity trade-offs. Households with high dependency near forest edges may inadvertently increase localized pressure on host trees, potentially leading to overharvesting and resource degradation. Similar patterns have been observed in other tropical forest contexts, where high-dependency households contribute disproportionately to localized deforestation and resource depletion (Sunderland et al., 2015; Sonwa et al., 2019). Understanding these spatially mediated dependency dynamics is critical for devising interventions that balance livelihood needs with forest conservation.

Gendered and age-based harvesting participation

Women and children constituted 72% of harvesters, reflecting entrenched gender and intergenerational labor divisions in rural forest-dependent communities. Women dominate collection and processing, consistent with broader literature indicating that NTFPs are often gendered in access and use, with women assuming key roles in household subsistence and income (Fleuret & Fleuret, 1980; Shackleton et al., 2007). Children's participation highlights intergenerational transmission of ecological knowledge and seasonal labor contributions, often linked to school calendars and labor-sharing practices (Ndoye & Tieguhong, 2004). These gendered and age-based

patterns have implications for both social equity and sustainability. Women and children's dominant participation increases household vulnerability if ecological degradation reduces available resources, potentially intensifying social inequities. Comparable studies in African forest settings reveal that interventions aimed at sustainable NTFP management must incorporate gender-sensitive strategies to mitigate negative impacts on primary collectors while enhancing livelihood resilience (FRA, 2015; Sunderland et al., 2015).

Gendered Participation and Implications in Caterpillar Harvesting

Women and children (aged 5–15 years) constituted 72% of caterpillar harvesters, with women alone accounting for 43.5% and children 28.5% (Table 6). This reflects entrenched gender norms in rural Congo Basin communities, where women and youth undertake labor-intensive, low-capital tasks such as climbing trees, collecting larvae, sorting, cleaning, smoking, drying, and local sales (Chakona & Shackleton, 2019; Womeni et al., 2016). Men (18%) and older youth (16–24 years, 10%) were primarily involved in physically demanding or higher-value activities, including branch cutting and transport to markets.

Thematic analysis from focus group discussions and key informant interviews revealed gendered disparities in both benefits and burdens. Women were primarily responsible for household-level processing and consumption, enhancing dietary diversity and food security, but had limited control over income from sales, which was often directed to family needs such as education or healthcare rather than personal accumulation. Cultural taboos in some communities, including restrictions during menstruation, further constrained women's access and participation (Madamo et al., 2025). Children's involvement, particularly during school holidays, contributed to family labor but raised concerns about trade-offs with education.

These patterns align with broader NTFP research showing women dominate subsistence-oriented segments yet face barriers to market information, value addition, and decision-making (Ingram et al., 2014; Sunderland et al., 2015). In the Yangambi context, women's heavy involvement increases vulnerability to resource decline, including longer collection distances and physical risks, but simultaneously positions them as key agents for sustainable harvesting practices if empowered through training, cooperatives, and gender-sensitive interventions.

Harvesting practices and ecological implications

Forest inventories revealed that primary forests maintain higher basal area, canopy cover, and species richness than secondary forests, with defoliation intensity higher in secondary forests. The negative correlation between basal area and harvesting intensity ($r = -0.45$) indicates that destructive practices reduce forest productivity, corroborating findings from similar Congo Basin studies where NTFP overharvesting undermines regeneration (Sonwa et al., 2019; Looli et al., 2021). Rapid rural appraisals and qualitative data confirmed destructive behaviors, such as branch breaking and selective felling, particularly for high-yield host species. Rapid Rural Appraisal trend lines over a 15-year retrospective indicate a perceived decline in caterpillar abundance and outbreak reliability since around 2003, with 65% of respondents reporting shorter seasons and lower yields. Key informants linked this decline to progressive depletion of host trees, particularly in secondary forests, where repeated defoliation and cutting reduce leaf flush capacity and regeneration. Forest inventories confirmed moderate to high defoliation intensity, averaging 41% in primary forests and higher in secondary forests, with a significant negative correlation to basal area ($r = -0.45$, $p < 0.05$), suggesting that intensive harvesting undermines tree health and future caterpillar hosting potential. Comparative studies from Kwilu Province and Luki Biosphere Reserve report similar patterns, where habitat fragmentation, selective logging of host species such as *Entandrophragma cylindricum*, and climatic irregularity have reduced caterpillar populations by 50–80% over the past two decades (Lonpi Tipi et al., 2025; Madamo et al., 2025). Without management focused on host-tree regeneration and sustainable harvesting, continued destructive practices risk creating a feedback loop of scarcity leading to intensified harvesting and further ecological degradation.

The ecological implications are significant. Continued pressure in secondary forests could lead to biodiversity loss, altered forest structure, and reduced NTFP yields, which in turn exacerbate household vulnerability, particularly among poor and proximate households. These findings reinforce the importance of integrated forest management, combining community-based monitoring, education, and alternative livelihood strategies, to maintain ecological integrity while supporting socio-economic needs (FAO, 2020; Agea et al., 2016).

The observed defoliation and long-term perceived decline in caterpillar populations highlight sustainability risks that extend beyond immediate livelihoods. Host trees in secondary forests, already structurally simplified, show lower resilience to repeated defoliation and cutting, potentially reducing regeneration rates and future outbreak capacity (Schabel, 2010; Zambaldi et al., 2020). While primary forests provide greater buffering due to higher basal area and canopy cover, proximity-driven dependence ($r = 0.67$) concentrates harvesting pressure near accessible remnants, threatening biodiversity and long-term provisioning services.

These patterns are consistent with broader Congo Basin evidence showing that unsustainable NTFP harvesting contributes to host-tree decline and reduced insect abundance (Muvatsi et al., 2021; Lonpi Tipi et al., 2025). Although the absence of longitudinal monitoring limits precise quantification of regeneration thresholds, qualitative trends and inventory data suggest current practices may exceed sustainable limits. Adoption of nondestructive harvesting techniques, such as ladder use and selective branch pruning, alongside host-tree enrichment planting, could mitigate these risks while maintaining critical livelihood benefits.

Seasonal patterns and climate considerations

Seasonal peak availability of edible caterpillars aligns with the agricultural lean period, highlighting their critical buffering function. Long-term climatic trends, including temperature increases and variable rainfall, may influence host tree phenology and caterpillar population dynamics, consistent with ecological observations in the Congo Basin (Sonwa et al., 2019; Zambaldi et al., 2020). While this study did not perform a full climate modeling analysis, local perceptions and RRA trends indicate that climatic variability is perceived to impact abundance and seasonality, reinforcing the need to consider climate-forest-livelihood linkages in adaptive management.

CONCLUSION

This study set out to empirically examine the socio-economic contribution of edible caterpillars to rural livelihoods in villages adjacent to the Yangambi Biosphere Reserve, within a socio-ecological systems context. Drawing on a convergent mixed-methods design, the findings demonstrate that edible caterpillars constitute a central livelihood asset rather than a marginal or supplementary activity. Their contribution to household income, particularly among asset-poor households, confirms their role as a critical component of livelihood resilience during periods of agricultural scarcity. The results further show that dependence on edible caterpillars is not randomly distributed but is strongly structured by spatial proximity to forest resources, wealth status, and entrenched gender and age-based labor divisions. From a theoretical standpoint, the findings reinforce the explanatory value of the Sustainable Livelihoods Framework by illustrating how natural capital compensates for deficits in financial and physical assets, especially among poorer households. Forest Dependency Theory is likewise substantiated, as households located closer to forest edges and possessing fewer alternative income sources exhibited higher dependency intensities. Importantly, the integration of forest inventory data with household-level socio-economic analysis reveals that livelihood dependence is occurring alongside ecological pressures, particularly in secondary forest zones where destructive harvesting practices are more prevalent and regeneration capacity is lower. Overall, the study confirms that edible caterpillars function simultaneously as a food security buffer, a cash income source, and a culturally embedded livelihood strategy. However, without targeted management interventions, proximity-driven dependency and unsustainable harvesting practices risk undermining both forest integrity and the long-term viability of this livelihood resource. The evidence underscores the need to move beyond simplistic conservation versus livelihood narratives toward integrated, context-sensitive governance approaches in biosphere reserve transition zones.

RECOMMENDATIONS

To ensure the long-term viability of edible caterpillars as a socio-economic resource while maintaining forest ecosystem integrity in the transition zones of the Yangambi Biosphere Reserve, the following integrated, evidence-based recommendations are proposed. First, implement sustainable and non-destructive harvesting practices by establishing community-level regulations that prohibit tree felling and promote techniques such as ladder use, selective branch pruning, and seasonal access that aligns with host-tree phenology. Training programs should focus on primary harvesters, predominantly women and children who constitute 72 % of participants, to reduce ecological damage, as 91.3 % of respondents currently report tree cutting, and to preserve host-tree

regeneration capacity. Second, promote host-tree restoration and enrichment planting by carrying out targeted reforestation and agroforestry initiatives focused on key caterpillar host species, including *Entandrophragma cylindricum* and *Petersianthus macrocarpus*, particularly in degraded secondary forests and buffer zones near villages with high dependence, defined as less than five kilometers from forest edges. These interventions aim to restore habitat quality, increase outbreak reliability, and mitigate perceived declines observed since 2003 due to structural degradation. Third, strengthen gender-responsive training and empowerment through capacity-building programs for women and youth, emphasizing sustainable harvesting techniques, value addition through improved smoking and drying methods, and entrepreneurship. The formation of women's cooperatives can enhance bargaining power, income control, and collective marketing, addressing inequities in value-chain returns and cultural constraints on participation. Fourth, enhance informal value chains and economic returns by facilitating market access, improving transport and storage infrastructure, and supporting small-scale processing and branding initiatives to capture higher value from seasonal trade. Caterpillars contribute an average of 32 % of seasonal household income, rising to 48 % for poor households, underscoring the importance of improving primary collectors' returns. Fifth, establish community-based long-term monitoring systems that involve local harvesters, women's groups, youth, and INERA researchers to track caterpillar abundance, host-tree health, regeneration rates, and climatic influences. Simple indicators, including outbreak timing and defoliation levels, should be used to identify early signs of unsustainability and inform adaptive management strategies. Sixth, integrate edible caterpillars into biosphere reserve governance by including high-value non-timber forest products in zoning regulations, management plans, and benefit-sharing frameworks, with gender-balanced representation to reflect the critical roles of women and youth while reconciling conservation objectives with livelihood needs. Finally, explore semi-domestication and diversified production systems by piloting controlled rearing on host trees or small-scale plantations and integrating caterpillar hosts within agroforestry systems alongside food crops. These strategies can reduce pressure on wild populations, stabilize seasonal supply, and provide alternative income pathways for vulnerable households. Implementation of these recommendations should occur through participatory, multi-stakeholder processes involving local communities, INERA, conservation agencies, and non-governmental organizations to ensure equity, ownership, and long-term sustainability.

Further research perspective

Future research should focus on a longitudinal assessment of edible caterpillar harvesting systems that combines repeated forest inventories, household income tracking, and climatic data to evaluate how interannual variability, ecological regeneration, and livelihood dependence interact over time. Such an approach would provide stronger causal insights into sustainability thresholds and inform adaptive management strategies under changing socio-environmental conditions.

ACKNOWLEDGEMENTS

The successful completion of this paper would not have been possible without the support, guidance, and contributions of numerous individuals and institutions. The Erasmus Mundus Scholarship Board for awarding Barika David Ngwa the scholarship that enabled him to undertake the two-year Master studies in Sustainable Tropical Forestry (SUTROFOR), jointly offered by the University of Copenhagen (Denmark) and the Technical University of Dresden (Germany) in 2010.

Special thanks to the Cameroon Government through the Ministry of Public Service and Administrative Reforms for offering me a study leave to pursue further studies internationally. I equally wish to thank my wife Mah Lilian Mbuh and four children who remained steadfast during my absence.

REFERENCES

1. Agea, J. G., Biryomumaisho, D., Buyinza, M., & Nabanoga, G. N. (2016). Commercialisation of edible insects in Uganda: Drivers, challenges, and opportunities. Journal of Insects as Food and Feed, 2(2), 85–96. https://doi.org/10.3920/JIFF2015.0053
2. Angelsen, A., Jagger, P., Babigumira, R., Belcher, B., Hogarth, N. J., Bauch, S., Börner, J., Smith-Hall, C., & Wunder, S. (2014). Environmental income and rural livelihoods: A global comparative analysis. World Development, 64(Suppl. 1), S12–S28. https://doi.org/10.1016/j.worlddev.2014.03.006

3. Ayieko, M. A., Oriaro, V., & Nyambuga, I. A. (2012). Processed products of termites and lake flies: Improving entomophagy for food security in Africa. Journal of Food Processing & Preservation, 36(6), 466–476. https://doi.org/10.1111/j.1745-4549.2011.00607.x
4. Chakona, G., & Shackleton, C. M. (2019). The contribution of edible insects to household food security in rural Limpopo, South Africa. Food Security, 11(1), 189–203. https://doi.org/10.1007/s12571-0180876-9
5. Chapman, C. A., Chapman, L. J., Vulinec, K., Zanne, A. E., & Lawes, M. J. (2005). A long-term evaluation of fruiting phenology: Importance of climate change. Journal of Tropical Ecology, 21(1), 31–45. https://doi.org/10.1017/S0266467404001991
6. Creswell, J. W., & Plano Clark, V. L. (2018). Designing and conducting mixed methods research (3rd ed.). SAGE Publications.
7. FAO. (2020). Global forest resources assessment 2020. Food and Agriculture Organization of the United Nations.
8. Hanboonsong, Y., & Durst, P. B. (2020). Edible insects in Lao PDR: Building on tradition to enhance food security. FAO Asia-Pacific Forestry Sector Outlook Study II.
9. Ingram, V., Ndoye, O., Iponga, D. M., Tieguhong, J. C., & Nasi, R. (2014). Non-timber forest products: Contribution to national economy and strategies for sustainable management. International Forestry Review, 16(3), 300–316. https://doi.org/10.1505/146554814812572449
10. IPCC. (2022). Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009325844
11. Lonpi Tipi, E., Mpanda Mukenza, M., Useni Sikuzani, Y., Messina Ndzomo, J.-P., Sambieni Kouagou, R., Malaisse, F., Lumande Kasali, J., Khasa, D., & Bogaert, J. (2025). Dynamics and anthropisation of edible caterpillar habitats in the landscape of the Luki Biosphere Reserve, Democratic Republic of the Congo. Land, 14(7), Article 1384. https://doi.org/10.3390/land14071384
12. Looli, G., Sonwa, D. J., & Eba'a Atyi, R. (2021). Forest degradation and livelihood vulnerability in Central
13. Africa. Forest Policy and Economics, 123, Article 102356. https://doi.org/10.1016/j.forpol.2020.102356 13. Madamo, F. M., Cokola, M. C., Gougbedji, A., ... (2025). Edible caterpillars and their host plants: Ethnobotanical insights in Kwilu, Democratic Republic of Congo. Journal of Ethnobiology and Ethnomedicine, 21, Article 33. https://doi.org/10.1186/s13002-025-00781-5
14. Malaise, F. (2002). How to live and survive in Zambezian open forest. Les Presses Agronomiques de Gembloux.
15. Muvatsi, P., Kahindo, J.-M., & Sonwa, D. J. (2021). Edible insects in the Democratic Republic of Congo: Opportunities and challenges. Journal of Insects as Food and Feed, 7(4), 465–478. https://doi.org/10.3920/JIFF2020.0087
16. Ndoye, O., & Tieguhong, J. C. (2004). Forest resources and rural livelihoods: The conflict between timber and non-timber forest products in the Congo Basin. Scandinavian Journal of Forest Research, 19(S4), 36–44. https://doi.org/10.1080/14004080410034151
17. N'Gasse, G. (2004). Les chenilles comestibles en Afrique centrale: Valeur nutritionnelle et économique. Tropicultura, 22(4), 177–184.
18. Ramos-Elorduy, J. (2009). Anthropo-entomophagy: Cultures, evolution and sustainability. Entomological Research, 39(5), 271–288. https://doi.org/10.1111/j.1748-5967.2009.00238.x
19. Schabel, H. G. (2010). Forest entomology in Africa. Springer.
20. Sonwa, D. J., Weise, S., Nkongmeneck, B. A., & Tchatat, M. (2019). Climate change and forests in Central Africa (CIFOR Occasional Paper No. 190). Center for International Forestry Research.
21. Sunderland, T. C. H., Powell, B., Ickowitz, A., Foli, S., Pinedo-Vasquez, M., & Nasi, R. (2015). Food security and nutrition: The role of forests. International Forestry Review, 17(S2), 1–7.
22. https://doi.org/10.1505/146554815816086444
23. UNESCO. (2023). Yangambi Biosphere Reserve profile. Man and the Biosphere Programme. https://en.unesco.org/biosphere/africa/yangambi
24. van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., & Vantomme, P. (2013). Edible insects: Future prospects for food and feed security (FAO Forestry Paper No. 171). Food and Agriculture Organization of the United Nations.

25. Vantomme, P., Göhler, D., & N'Deckere-Ziangba, F. (2004). Contribution of forest insects to food security. Unasylva, 55(218), 11–17.
26. Womeni, H. M., Linder, M., Tiencheu, B., Mbiapo, F. T., Villeneuve, P., & Fanni, J. (2016). Oils of insects and larvae. Food Chemistry, 207, 175–182. https://doi.org/10.1016/j.foodchem.2016.03.089
27. Zambaldi, E., Ahn, E., & Kim, H. (2020). Nutritional composition of edible insects. Journal of Asia-Pacific Entomology, 23(2), 384–393. https://doi.org/10.1016/j.aspen.2020.02.005