BIODIVERSITAS
Volume 27, Number 4, April 2026
Pages: 13

ISSN: 1412-033X
E-ISSN: 2085-4722
https://doi.org/10.13057/biodiv/d270418

Diversity and spatial distribution of non-timber forest products in the Mamasa sub-watershed, Sulawesi, Indonesia

MUHAMMAD ALRIEFQI PALGUNADI[1,♥], ACHMAD FUAD FATHURRAHMAN[2,3]
[1]Faculty of Forestry and Tropical Environment, Universitas Mulawarman. Jl. Penajam, Samarinda 75119, East Kalimantan, Indonesia.
Tel.: +62-541-749068, Fax.: +62-541-735379, ♥email: muhammad.alriefqi@fahutan.unmul.ac.id
[2]Asian School of The Environment, Nanyang Technological University. 50 Nanyang Avenue 639798, Singapore
[3]Faculty of Science and Technology, Universitas Cahaya Prima. Jl. Jendral Urip Sumoharjo Km 1.5, Watampone 92711, South Sulawesi, Indonesia

Manuscript received: 22 December 2025. Revision accepted: 13 April 2026

Abstract. *Palgunadi MA, Fathurrahman AF. 2026. Diversity and spatial distribution of non-timber forest products in the Mamasa sub-watershed, Sulawesi, Indonesia. Biodiversitas 27 (4): d270418. https://doi.org/10.13057/biodiv/d270418.* Mamasa sub-watershed is undergoing rapid ecological degradation driven by land-use change, yet its potential for biodiversity-based livelihood strategies, especially through Non-Timber Forest Products (NTFPs), remains poorly documented. This study addresses this gap by conducting a comprehensive NTFP inventory and spatial assessment to support ecosystem-based watershed management. A stratified systematic sampling with random start design was applied using 154 cluster plots across the 104,680.52 ha sub-watershed. Species density, relative frequency, and Importance Value Index (IVI) were quantified, followed by spatial analysis of NTFP distribution patterns. Utilization categories were assigned based on established literature rather than household surveys, providing an assessment of potential functional uses instead of site-specific extraction practices. A total of 84 NTFP species were recorded. *Pinus merkusii* was the most dominant species (RD 16.21%; IVI 22.03), while *Arenga pinnata* showed the widest spatial distribution (RF 9.80%; IVI 16.16), followed by ecologically resilient understory species such as *Cyathea arborea*, *Calamus rotang*, and *Diplazium esculentum*. Spatial analysis based on mapped distribution indicated visually clustered patterns of high-value NTFPs across secondary forests, riparian corridors, and forest–agriculture interfaces. These findings indicate that NTFPs may function as important ecological and potentially socio-economic components of the Mamasa watershed. While no livelihood or income data were collected in this study, the documented species and their literature-based uses suggest potential pathways for ecosystem-supportive and sustainable livelihood opportunities. These results provide a spatially explicit basis for targeted NTFP zoning, enrichment planting in degraded areas, and the development of sustainable NTFP-based livelihood strategies that simultaneously strengthen ecosystem resilience and watershed management.

Keywords: Conservation, inventory, Mamasa watershed, NTFPs, sustainable livelihoods

INTRODUCTION

Indonesia hosts one of the largest extents of tropical forests globally, playing a critical role in biodiversity conservation, climate regulation, and hydrological stability (Archibold 1995; Borma 2023). These forests support complex ecological processes, including carbon sequestration, nutrient cycling, and water regulation, while simultaneously sustaining human livelihoods across forested landscapes. Among these landscapes, watersheds represent fundamental ecological units that integrate terrestrial and aquatic processes, linking vegetation structure, soil stability, and hydrological dynamics across spatial scales (Flotemersch et al. 2016; Springgay 2017). As such, forest condition within watersheds strongly determines ecosystem resilience and the sustainability of ecosystem services.

Despite their importance, many Indonesian watersheds are experiencing accelerating degradation driven by deforestation, agricultural expansion, and unsustainable land-use practices. National assessments indicate that many watersheds are classified as critical or potentially critical, resulting in increased erosion, sedimentation, floods, and landslides (Scholten and Seitz 2019). These pressures are intensified by climate change, amplifying hydrological variability and disturbance regimes. Addressing watershed degradation requires management approaches that restore ecological functions while remaining compatible with local livelihood needs (Pacheco and Fernandes 2020). In response, there is growing recognition of the need to upscale forest landscape restoration to restore hydrological stability, biodiversity, and ecosystem services. Recent studies emphasize that large-scale restoration initiatives must integrate ecological recovery with community participation and sustainable livelihood opportunities to achieve long-term success (Budiharta and Holl 2025).

One of the most ecologically and socio-economically important yet increasingly degraded landscapes in Indonesia is the Mamasa River sub-watershed, part of the Saddang River system, a major basin in western Sulawesi. Located in West Sulawesi and extending into South Sulawesi, this mountainous area plays a key role in regulating hydrological processes within the watershed. Situated in the Wallacea biogeographic zone, it spans more than 100,000 ha and supports high biodiversity and endemism, while sustaining rural livelihoods dependent on agriculture and forest resources (Hoggarth et al. 1998). However, rapid land-use change, particularly forest conversion to agriculture, has weakened watershed functions and increased vulnerability to hydrological hazards. Recent flood events in Mamasa highlight growing risks associated with declining forest cover and landscape fragmentation.

Within this context, non-timber forest products (NTFPs) represent a promising yet underexplored mechanism linking biodiversity conservation with sustainable livelihoods. NTFPs (including fruits, resins, rattans, medicinal plants, ornamental species, and forest honey) can be harvested with relatively low ecological impact while maintaining forest structure and ecosystem functions (Dyck 2022). Studies across Indonesia show that NTFPs contribute to income diversification, reduce reliance on timber extraction, and mitigate pressures from illegal logging and land conversion (Latifah et al. 2020; Pandiangan et al. 2023). In watershed landscapes, NTFPs may also promote forest retention in secondary forests, riparian corridors, and forest-agriculture interfaces critical for hydrological regulation (Brancalion et al. 2019).

Despite these recognized benefits, studies examining NTFPs within a watershed-scale ecological context remain limited in Indonesia. Most research has focused on ethnobotanical documentation or household-level utilization, with little attention to spatial distribution and ecological roles of NTFPs across watershed landscapes. In contrast, studies in other regions have demonstrated the importance of watershed-based assessments for understanding the diversity and management potential of NTFPs, including research in the Himalayan region, China's Naban River watershed, and the Chesapeake Bay watershed (Singh 1999; Ghorbani et al. 2012; Robles-Diaz-de-Leon and Kangas 1998).

Addressing this gap is essential for advancing ecosystem-based watershed management in Mamasa. Understanding which NTFP species occur, how they are structurally organized, how their potential uses are distributed, and where high-value species are spatially concentrated can inform targeted interventions such as enrichment planting, zoning, and sustainable harvesting schemes. Moreover, spatially explicit NTFP information can support administrative-level planning by identifying villages and landscape elements with high potential for NTFP-based livelihood development.

Accordingly, this study conducts a comprehensive inventory and spatial analysis of Non-Timber Forest Products in the Mamasa River sub-watershed, Indonesia. Specifically, it aims to: (i) quantify species diversity and structural patterns of NTFPs using density, frequency, and Importance Value Index metrics, (ii) describe utilization-based diversity based on literature-derived functional categories, and (iii) map administrative-based distribution and assess landscape-level implications of dominant NTFP species. By integrating field-based inventory with spatial analysis, this study provides a foundation for incorporating NTFPs into watershed management frameworks that support biodiversity conservation, ecosystem resilience, and sustainable rural livelihoods.

MATERIALS AND METHODS

Study area

The Mamasa sub-watershed is administratively located in West Sulawesi Province, Indonesia, primarily within Mamasa District and partially extending into neighboring areas of South Sulawesi Province, forming part of the larger Saddang River watershed system. The study area is situated approximately between 2º45'-3º20'S and 119º10'-119º45'E in the western part of Sulawesi Island (Figure 1). The region is predominantly mountainous, with elevations ranging from 200 to over 2,000 meters above sea level, resulting in a tropical climate with high rainfall and clearly defined wet and dry seasons. Situated within the Wallacea biogeographical region, which represents a transitional zone between the Asian and Australian faunal realms, the Sub-watershed of the Mamasa River supports high levels of endemic biodiversity. It is home to several unique species, including the critically endangered lowland and mountain anoa (*Bubalus depressicornis* and *Bubalus quarlesi*), highlighting its ecological significance and role as a refuge for distinctive wildlife.

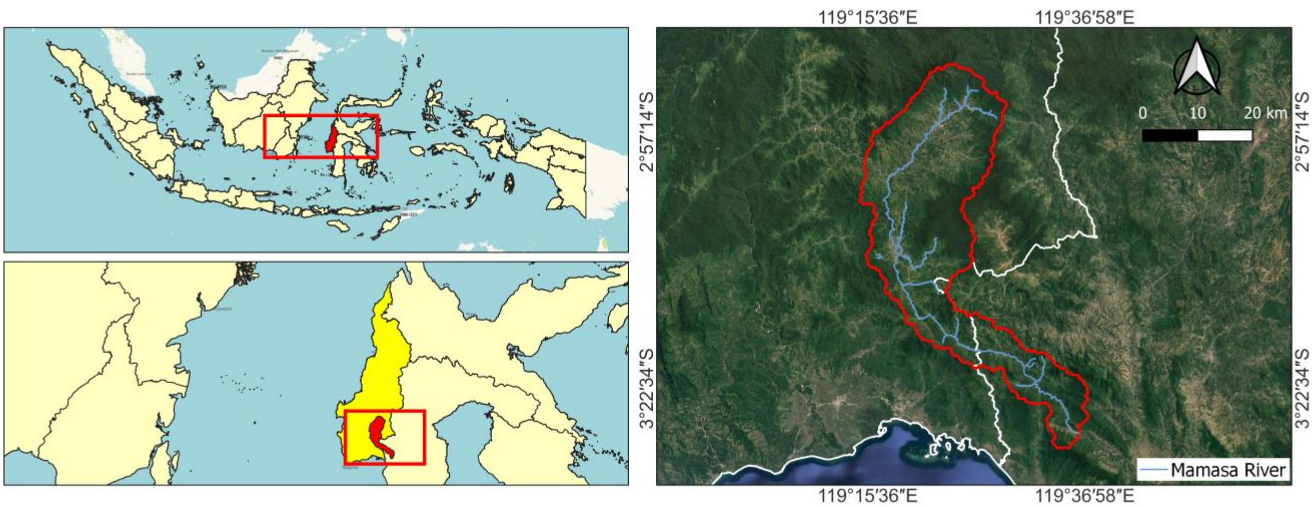

Figure 1. Location and boundary of the Mamasa Sub-watershed in West Sulawesi, Indonesia

The Sub-watershed of the Mamasa River covers an area of 104,680.52 ha (Minister of Environment and Forestry Decree No.304/MenLHK/PDASHL/DAS.0/7/2018 on the Designation of Watersheds) and is predominantly rural. Most people inhabiting the area largely depend on agriculture as their primary livelihood. Common crops include rice, maize, and various horticultural products. The majority of the sub-watershed area lies within Mamasa District and is inhabited mainly by the Mamasa people, who share close cultural ties with the Toraja ethnic group and maintain strong communal traditions. Socio-economic development programs in the region focus on improving education, health, and agricultural productivity while promoting sustainable natural resource management (Figure 1).

The landscape of the Mamasa sub-watershed consists of a mosaic of forest ecosystems, agricultural land, and rural settlements. Forest cover remains dominant, including primary and secondary dryland forests, while other land uses include dryland farming, rice fields, shrublands, and small settlements. Parts of the forested area fall within Indonesia's state forest zone (*kawasan hutan*) and are managed by government Forest Management Units (*Kesatuan Pengelolaan Hutan/KPH*), including KPH Mamasa Tengah and Mamasa Timur, with legal designations such as protection forest (*hutan lindung*) and production forest (*hutan produksi*). Areas outside the state forest zone are largely managed by local communities through smallholder agriculture, agroforestry systems, and mixed gardens (Soma et al. 2023).

Research procedures

Sampling design

The inventory of Non-Timber Forest Products (NTFPs) across a sub-watershed area of 104,680.52 ha was conducted in December 2024 using a Stratified Systematic Sampling with Random Start design. Stratification was based on land-cover density classes derived from existing land-cover maps, which were grouped into dense vegetation cover and sparse vegetation cover to represent variation in forest structure and canopy condition across the sub-watershed. Sampling intensity was adjusted according to these strata, with a higher number of plots allocated to areas with denser vegetation cover to better capture NTFP diversity and structural variability. Because sampling focused more on dense vegetation strata, NTFP abundance and diversity in cultivated and settlement-dominated areas may be underrepresented. Therefore, the findings mainly reflect forest and semi-forest parts of the sub-watershed rather than the full land-use mosaic.

Sampling locations were initially selected randomly within each stratum and subsequently arranged systematically at approximately 3 km intervals in a grid aligned with the cardinal directions to ensure even spatial coverage across the sub-watershed. In total, 154 sampling units were established. Each sampling unit consisted of five circular plots, each covering 0.1 ha (radius = 17.8 m), resulting in a total area of 0.5 ha per sampling unit. Therefore, the cumulative sampled area was 77 ha, corresponding to a sampling intensity of approximately 0.07% of the total sub-watershed area. Plot placement was determined based on land-cover density strata and systematic spacing rather than village administrative boundaries.

Plot configuration and vegetation measurement

Within each circular plot, a nested subplot design was used to record vegetation and non-timber forest products (NTFPs) at different growth stages: seedlings, herbs, ferns, and fungi (<1.5 m height) were recorded within a 2 m radius subplot; saplings (DBH <5 cm) within a 5 m radius subplot; poles and young rattans (DBH 5-20 cm, stem height <3 m) within a 10 m radius subplot; and mature rattans, bamboo, palms, and trees with DBH >20 cm within the full plot area. This hierarchical nested design allowed standardized assessment of both understory and canopy-associated NTFPs, facilitating comparisons of density and frequency across life stages and growth forms. The spatial configuration of cluster plots and nested subplots is illustrated in Figure 2. The sampling design and plot configuration followed the regulation of the Director General of Spatial Planning and Environmental Governance Number. P. 1/PKTL/IPSDH/PLA.1/I/2017.

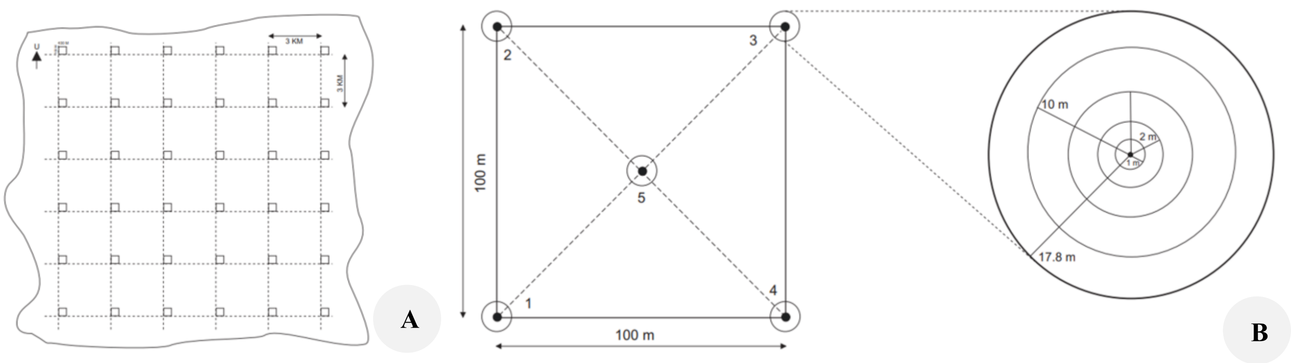

Figure 2. Sampling design for the NTFP inventory in the Mamasa sub-watershed. A. Systematic distribution of cluster plots at approximately 3 km intervals following a random start. B. Cluster plot design showing five nested circular plots (0.1 ha each) within a 100 m × 100 m sampling unit, with concentric subplots used to record different growth forms and size classes

Data analysis

Species diversity and structure

The data collected from the field were compiled into tabular form and subsequently subjected to quantitative analysis to determine species density, frequency, and Importance Value Index (IVI), providing a detailed assessment of the composition, abundance, and ecological significance of NTFP species within the study area. Relative density (RD), relative frequency (RF), and Importance value index (IVI) were calculated as follows:

$$RD_i = \frac{n_i}{\sum n} \times 100 \quad [1]$$

$$RF_i = \frac{p_i}{P} \times 100 \quad [2]$$

$$IVI_i = RD_i + RF_i \quad [3]$$

Where n_i is the number of individuals of species *i*, $\sum n$ is the total number of individuals of all species, p_i is the number of plots in which species *i* occurs, and P is the total number of sampling plots. This modified IVI formulation is appropriate for NTFP-focused assessments where species abundance and spatial occurrence are more informative than basal area or dominance (Permatasari et al. 2024).

Relative density (RD) and Relative frequency (RF) were calculated based on the nested subplot design (0.1 ha for trees ≥10 cm DBH; 10 m × 10 m for poles/saplings; 5 m × 5 m for seedlings and shrubs; and 2 m × 2 m for herbs and ground vegetation). Counting rules were standardized across growth forms: each stem meeting the DBH threshold was recorded as one individual; multi-stemmed trees from a single root system and bamboo clumps were treated as one individual; herbs and shrubs were counted per rootstock; climbers were recorded if rooted within the subplot; epiphytes per discrete clump; and fungi per distinct fruiting cluster on a single substrate. All individuals were then analyzed collectively to provide a general overview of community structure while minimizing overestimation of clonal organisms and ensuring methodological transparency.

Non-timber forest products utilization

The categorization of NTFP species into utilization groups in this study represents a literature-based synthesis applied to the field inventory rather than a direct assessment of local use practices. This approach allows the utilization-based diversity analysis to highlight the potential functional and socio-economic roles of recorded species within broader NTFP frameworks, while avoiding overinterpretation of site-specific ethnobotanical knowledge. Consequently, the utilization patterns discussed here should be interpreted as indicative of potential uses, providing a standardized basis for comparative analysis and informing future studies that explicitly incorporate local knowledge and ethnobotanical survey. This study did not collect socio-economic or household-level data, any discussion of livelihood relevance is based on documented uses in the literature rather than measured economic outcomes within the study area.

Non-timber forest products spatial distribution

Subsequently, the area of sub-watershed of the Mamasa River was delineated using a digital elevation model (DEM) obtained from the Indonesian Geospatial Information Agency (https://tanahair.indonesia.go.id). All spatial analyses were conducted in QGIS version 3.40.13, with the DEM projected to the WGS 84/UTM Zone 50S coordinate reference system to ensure spatial accuracy. The delineated sub-watershed boundary was subsequently overlaid with village administrative boundaries to identify villages located within the sub-watershed. Spatial distribution maps were then generated to visualize the occurrence and distribution patterns of non-timber forest products (NTFPs) species across the sub-watershed, providing a spatial framework for interpreting landscape-level distribution patterns. Spatial patterns of species distribution were assessed descriptively based on visual interpretation of distribution maps. This spatially explicit but descriptive approach facilitates the identification of areas with relatively high NTFP occurrence and supports management-oriented interpretation, such as highlighting potential zones for conservation, enrichment planting, and sustainable resource utilization (Brancalion et al. 2019; Poorter et al. 2021).

RESULTS AND DISCUSSION

Species diversity and structural patterns of NTFP species

A total of 84 non-timber forest product (NTFP) species were identified across the Mamasa sub-watershed, representing a wide range of ecological functions, taxonomic groups and vegetation strata (Table 1). The presence of canopy trees, palms, rattans, understory herbs, climbers, epiphytes, and fungi indicates a vertically structured and functionally diverse forest system. Rather than providing a comparative measure of diversity, this assemblage documents the coexistence of multiple functional groups across distinct vegetation layers. The persistence of NTFPs across vertical layers suggests that, despite land-use pressure, the sub-watershed retains structural complexity that supports habitat heterogeneity and localized microclimatic variation, both of which are important for maintaining ecological processes in disturbed tropical forest landscapes (Sulistyawati et al. 2018; Rohani et al. 2020; Elias et al. 2024).

During field sampling, wild honeybees, including *Trigona* spp. and *Apis* spp., were observed in association with flowering NTFP species such as *Arenga pinnata*, *Pandanus tectorius*, and *Aleurites moluccanus*, providing continuous nectar and pollen resources that sustain local pollinator populations (Anita et al. 2022). The availability of nectar- and pollen-producing NTFPs suggests that the sub-watershed continues to provide resources that may support pollinator presence. However, pollinator diversity, abundance, and visitation rates were not systematically quantified in this study. As such, these observations should be interpreted as indicative rather than conclusive evidence of functional plant-pollinator interactions, consistent with findings that emphasize the importance of forest structure for pollinator persistence while cautioning against inference without direct measurements (Ulyshen et al. 2023).

Table 1. Composition, relative density, relative frequency, and importance value index (IVI) of non-timber forest product (NTFPs) Species in the Mamasa sub-watershed

Species	Family	Category	Relative density (%)	Relative frequency (%)	IVI
Pinus merkusii Jungh. & de Vriese	Pinaceae	Tree	16.214	5.819	22.033
Arenga pinnata (Wurmb) Merr.	Arecaceae	Palm	6.362	9.801	16.163
Cyathea arborea (L.) Sm.	Cyatheaceae	Herb	9.717	5.36	15.077
Calamus rotang L.	Arecaceae	Palm/Rattan	5.062	7.657	12.719
Diplazium esculentum (Retz.) Sw.	Athyriaceae	Herb	5.217	4.747	9.964
Pandanus tectorius Parkinson ex Du Roi	Pandanaceae	Herb	4.655	4.9	9.555
Aleurites moluccanus (L.) Willd.	Euphorbiaceae	Tree	5.644	3.828	9.472
Theobroma cacao L.	Malvaceae	Tree	4.694	4.135	8.829
Coffea canephora Pierre ex A.Froehner	Rubiaceae	Tree	3.821	3.216	7.037
Bambusa sp.	Poaceae	Herb	1.823	4.441	6.264
Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	Herb	5.004	0.919	5.923
Asplenium nidus L.	Aspleniaceae	Herb	1.416	3.063	4.479
Mangifera sp.	Anacardiaceae	Tree	0.97	3.063	4.033
Cinnamomum burmannii (Nees & T.Nees) Blume	Lauraceae	Tree	1.067	1.838	2.905
Alpinia galanga (L.) Willd.	Zingiberaceae	Herb	1.241	1.378	2.619
Persea americana Mill.	Lauraceae	Tree	0.756	1.838	2.594
Pleurotus ostreatus (Jacq.) P.Kumm.	Pleurotaceae	Fungi	0.912	1.531	2.443
Pandanus amaryllifolius Roxb. ex Lindl.	Pandanaceae	Herb	1.299	1.072	2.371
Lansium domesticum Corrêa	Meliaceae	Tree	1.009	1.225	2.234
Cymbidium dayanum Rchb.f.	Orchidaceae	Herb	0.989	1.225	2.214
Durio zibethinus Murray	Malvaceae	Tree	0.892	1.225	2.117
Hellenia speciosa (J.Koenig) S.R.Dutta	Costaceae	Herb	0.582	1.531	2.113
Zingiber officinale Roscoe	Zingiberaceae	Herb	0.679	1.378	2.057
Phalaenopsis amabilis (L.) Blume	Orchidaceae	Herb	0.815	1.072	1.887
Etlingera elatior (Jack) R.M.Sm.	Zingiberaceae	Herb	0.795	1.072	1.867
Piper betle L.	Piperaceae	Herb	0.213	1.378	1.591
Dillenia serrata Thunb.	Dilleniaceae	Tree	0.485	1.072	1.557
Physalis angulata L.	Solanaceae	Herb	1.396	0.153	1.549
Dracontomelon dao (Blanco) Merr. & Rolfe	Anacardiaceae	Tree	0.31	1.072	1.382
Areca catechu L.	Arecaceae	Palm	0.582	0.766	1.348
Spondias dulcis Parkinson	Anacardiaceae	Tree	0.504	0.766	1.27
Alpinia purpurata (Vieill.) K.Schum.	Zingiberaceae	Herb	0.33	0.919	1.249
Impatiens platypetala Lindl.	Balsaminaceae	Herb	0.912	0.306	1.218
Musa balbisiana Colla	Musaceae	Herb	0.291	0.919	1.21
Dioscorea hispida Dennst.	Dioscoreaceae	Herb	0.194	0.919	1.113
Ficus racemosa L.	Moraceae	Tree	0.272	0.766	1.038
Colocasia esculenta (L.) Schott	Araceae	Herb	0.388	0.613	1.001
Rhynchostylis retusa (L.) Blume	Orchidaceae	Herb	0.33	0.613	0.943
Artocarpus heterophyllus Lam.	Moraceae	Tree	0.33	0.613	0.943
Metroxylon sagu Rottb.	Arecaceae	Palm	0.31	0.613	0.923
Ganoderma lucidum (Curtis) P.Karst.	Ganodermataceae	Fungi	0.601	0.306	0.907
Anacardium occidentale L.	Anacardiaceae	Tree	0.524	0.306	0.83
Auricularia auricula-judae (Bull.) Quél.	Auriculariaceae	Fungi	0.524	0.306	0.83
Coleus scutellarioides (L.) Benth.	Lamiaceae	Herb	0.194	0.613	0.807
Cenchrus purpureus (Schumach.) Morrone	Poaceae	herb	0.31	0.459	0.769
Dendrobium crumenatum Sw.	Orchidaceae	Herb	0.291	0.459	0.75
Antidesma bunius (L.) Spreng.	Phyllanthaceae	Tree	0.116	0.613	0.729
Nephelium lappaceum L.	Sapindaceae	Tree	0.213	0.459	0.672
Curcuma caesia Roxb.	Zingiberaceae	Herb	0.465	0.153	0.618
Grifola frondosa (Dicks.) Gray	Meripilaceae	Fungi	0.446	0.153	0.599
Pandanus tectorius Parkinson	Pandanaceae	Herb	0.272	0.306	0.578
Amorphophallus sp.	Araceae	Herb	0.252	0.306	0.558
Curcuma longa L.	Zingiberaceae	Herb	0.388	0.153	0.541
Passiflora foetida L.	Passifloraceae	Herb	0.388	0.153	0.541
Pigafetta elata (Mart.) H.Wendl.	Arecaceae	Palm	0.078	0.459	0.537
Artocarpus altilis (Parkinson) Fosberg	Moraceae	Tree	0.213	0.306	0.519
Vanilla planifolia Andrews	Orchidaceae	Herb	0.33	0.153	0.483
Monstera adansonii Schott	Araceae	Herb	0.175	0.306	0.481
Gossypium arboreum L.	Malvaceae	Tree	0.175	0.306	0.481
Cymbopogon citratus (DC.) Stapf	Poaceae	Herb	0.155	0.306	0.461
Lantana camara L.	Verbenaceae	Herb	0.272	0.153	0.425
Caryota mitis Lour.	Arecaceae	Palm	0.116	0.306	0.422

Rubus sp.	Rosaceae	Herb	0.116	0.306	0.422
Morus sp.	Moraceae	Herb	0.097	0.306	0.403
Volvariella volvacea (Bull.) Singer	Pluteaceae	Fungi	0.213	0.153	0.366
Tradescantia zebrina Bosse	Commelinaceae	Herb	0.213	0.153	0.366
Ficus variegata Blume	Moraceae	Tree	0.194	0.153	0.347
Averrhoa carambola L.	Oxalidaceae	Tree	0.136	0.153	0.289
Pluchea indica (L.) Less.	Asteraceae	Herb	0.136	0.153	0.289
Artocarpus altilis (Parkinson) Fosberg	Moraceae	Tree	0.097	0.153	0.25
Schleichera oleosa (Lour.) Oken	Sapindaceae	Tree	0.097	0.153	0.25
Sticherus flagellaris (Bory ex Willd.) Ching	Gleicheniaceae	Herb	0.097	0.153	0.25
Annona squamosa L.	Annonaceae	Tree	0.097	0.153	0.25
Curcuma zanthorrhiza Roxb.	Zingiberaceae	Herb	0.097	0.153	0.25
Dendrobium utile J.J.Sm.	Orchidaceae	Herb	0.078	0.153	0.231
Curcuma zedoaria (Christm.) Roscoe	Zingiberaceae	Herb	0.078	0.153	0.231
Averrhoa bilimbi L.	Oxalidaceae	Tree	0.039	0.153	0.192
Syzygium aqueum (Burm.f.) Alston	Myrtaceae	Tree	0.039	0.153	0.192
Syzygium polyanthum (Wight) Walp.	Myrtaceae	Tree	0.039	0.153	0.192
Dimocarpus longan Lour.	Sapindaceae	Tree	0.039	0.153	0.192
Psidium guajava L.	Myrtaceae	Tree	0.019	0.153	0.172
Syzygium malaccense (L.) Merr. & L.M.Perry	Myrtaceae	Tree	0.019	0.153	0.172
Aegle marmelos (L.) Corrêa	Rutaceae	Tree	0.019	0.153	0.172
Solanum nigrum L.	Solanaceae	Herb	0.019	0.153	0.172

The observed patterns of species diversity, structural dominance, and functional representation are consistent with those reported in forest systems that have undergone ecological reorganization, although this study's single-time inventory does not allow direct assessment of past trajectories in the Mamasa sub-watershed. Dominance by disturbance-tolerant canopy species alongside widely distributed understory NTFPs indicates the persistence of ecologically flexible taxa capable of occupying modified habitats. While the present study is based on a single cross-sectional inventory and does not directly quantify temporal dynamics or resilience, the observed vertical stratification and functional complementarity are consistent with tropical forest systems experiencing moderate disturbance, where retained structural complexity and functional redundancy support the continuation of key ecosystem processes (Brancalion et al. 2019; Poorter et al. 2021; Jiang et al. 2024). Together, these patterns suggest that NTFPs may persist across heterogeneous landscapes and potentially contribute to ecological functioning under land-use change, as documented in similar forest systems. These implications should be interpreted cautiously, as our inventory represents a single time-slice without temporal measurements.

Collectively, these findings suggest that the sub-watershed retains a structurally organized NTFP system that is likely capable of supporting key ecological processes, although these implications should be interpreted cautiously because no direct measurements of pollination, regeneration, or other ecological functions were conducted. The relative density (RD) and relative frequency (RF) values of the recorded species revealed pronounced structural differentiation within the non-timber forest product (NTFP) community. RD values ranged from 0.019 percent to 16.214 percent, with *Pinus merkusii* exhibiting the highest density, followed by *A. pinnata*. The observed dominance of *P. merkusii* is associated with a dense and spatially extensive canopy presence, suggesting that parts of the sub-watershed may be characterized by open or semi-open canopy conditions. As a disturbance-tolerant conifer adapted to dry and exposed environments, *P. merkusii* often proliferates in landscapes shaped by historical logging, fire, or land conversion, where competitive broadleaf species are reduced (Hartiningtias et al. 2020; Supartono et al. 2022). Its high density therefore, reflects not only species abundance but also the legacy of anthropogenic disturbance influencing forest structure, a pattern widely reported in secondary and production forests across Indonesia.

The high occurrence of *P. merkusii* in the study area is likely associated with historical plantation activities, as this species is not native to Sulawesi. In Indonesia, *P. merkusii* has been widely planted in state forest areas, particularly within Production Forest zones managed by government Forest Management Units, mainly for resin production and reforestation programs. In contrast, *A. pinnata* is a native species that commonly occurs both through natural regeneration and intentional retention or planting by local communities because of its economic value for sap, fiber, and food products. Therefore, the widespread distribution of *A. pinnata* in the Mamasa sub-watershed likely reflects a combination of natural growth and long-standing community management in agricultural and agroforestry landscapes.

In contrast, species with very low RD values, such as *Psidium guajava*, *Syzygium malaccense*, *Aegle marmelos*, and *Solanum nigrum*, exhibited restricted occurrence across the sampling plots. Such low densities likely indicate limited regeneration success, which may be associated with habitat degradation, competition for light, or nutrient limitation (Trouvé et al. 2019). These patterns suggest that not all NTFPs respond uniformly to disturbance and that species persistence is strongly mediated by local environmental filters.

Relative frequency values further emphasize differences in spatial occupancy among dominant taxa. RF values ranged from 0.153 percent to 9.801 percent, with *A. pinnata* exhibiting the highest frequency, indicating a wide and relatively even distribution across the sub-watershed.

This spatial pattern reflects the high ecological adaptability of *A. pinnata*, which thrives across diverse topographic positions and light conditions and functions as an important structural component in both secondary and disturbed forest stands (Li et al. 2020). Conversely, several species, such as *Physalis angulata*, *Curcuma* spp., *Passiflora foetida*, *Vanilla planifolia*, and various fruit tree species, exhibited the lowest RF values, suggesting that these species occurred sporadically and were restricted to particular sites within the observed watershed. Such spatial restriction may be associated with specific habitat requirements, localized anthropogenic planting, or limited tolerance to environmental heterogeneity within watershed ecosystems (Wierzcholska et al. 2020).

The Importance Value Index (IVI), calculated using relative density and relative frequency, provided an integrated measure of structural dominance within the NTFP assemblage. This approach is particularly appropriate for NTFPs-oriented ecosystems, where palms, rattans, bamboos, and medicinal herbs are better represented by abundance and spatial occurrence than by basal area or canopy cover (Curtis and McIntosh 1951; Mueller-Dombois and Ellenberg 1974). *P. merkusii* recorded the highest IVI value, followed by *A. pinnata*, *Cyathea arborea*, *Calamus rotang*, and *Diplazium esculentum*. Together, these taxa constitute the ecological core of the community, contributing disproportionately to forest structure, understory dynamics, and overall functional integrity of the NTFPs assemblage.

Utilization-based diversity of NTFP species

The non-timber forest product (NTFP) species are classified into five utilization categories, namely edible plants (E), medicinal and nutraceutical plants (M), ornamental and flowering plants (F), natural resins (N), and handicraft materials (C), highlights the multifunctional role of forest ecosystems within the Sub-watershed of the Mamasa River (Table 2). This utilization-based diversity reflects not only species richness, but also the integration of ecological functions, cultural practices, and livelihood strategies that have co-evolved with forest landscapes. Similar patterns have been documented across tropical forest regions, where NTFPs function as critical links between biodiversity conservation and socio-economic resilience (Dyck 2022; Chew et al. 2023).

Edible plants constitute the largest utilization category, encompassing a wide range of fruits, rhizomes, palms, fungi, and leafy vegetables. The dominance of this group highlights the potential role of NTFPs in supporting food availability in forest-adjacent landscapes, particularly in contexts where access to external food systems may be limited.

Tree-based fruits such as *Durio zibethinus* (durian), *Mangifera* sp. (mango), *Artocarpus heterophyllus* (jackfruit), and *Annona squamosa* (sugar apple) are widely recognized in the literature as seasonal sources of dietary nutrients, while rhizomatous species including *Curcuma longa* (turmeric), *Alpinia galanga* (galangal), and *Hellenia speciosa* (crepe ginger), are commonly reported as food plants with additional medicinal properties. Palms such as *A. pinnata* (sugar palm) and *Metroxylon sagu* (sago palm) are similarly documented as important carbohydrate sources that can be harvested while maintaining standing forest structure. The inclusion of multiple edible fungi species, including *Pleurotus ostreatus* and *Ganoderma lucidum*, further illustrates the diversity of forest-derived food resources. While this study did not quantify consumption frequency or household-level contributions, comparable studies across Southeast Asia have shown that edible NTFPs act as livelihood safety nets and income buffers under fluctuating environmental and economic conditions (Latifah et al. 2020; Pandiangan et al. 2023).

Medicinal and nutraceutical NTFPs form a substantial component of utilization diversity, reflecting the continued reliance on traditional health systems and ethnobotanical knowledge. Species such *Chromolaena odorata* (siam weed), *Pluchea indica* (Indian camphorweed), *Piper betle* (betel leaf), and *Cinnamomum burmannii* (cinnamon) are widely used in traditional remedies for treating infections, inflammation, and digestive disorders (Tlau and Lalawmpuii 2020; Ajay et al. 2021; Kumari et al. 2024). In addition, honey produced by *Apis mellifera*, *Apis cerana*, and *Trigona* sp. represents an important forest-derived nutraceutical product, combining dietary value with medicinal applications. While this study did not quantify household-level use or income contribution, previous studies have shown that forest-based beekeeping can enhance household income while reinforcing ecosystem services such as pollination (Harianja et al. 2023; Gyeltshen et al. 2024). Accordingly, the presence of medicinal plants and honey-producing species in the sub-watershed indicates the potential for NTFPs to contribute to health resilience and livelihood diversification, rather than measured socio-economic outcomes within the present study.

Ornamental and flowering plants also represent a significant utilization group, particularly through the presence of orchids, ferns, and decorative foliage species. Species such as *Phalaenopsis amabilis* (moon orchid), *Rhynchostylis retusa* (foxtail orchid), *Dendrobium crumenatum* (pigeon orchid), *Monstera adansonii*, *Tradescantia zebrina*, *Asplenium nidus* (bird's nest fern) and *C. arborea* (tree fern) possess high aesthetic and commercial value, offering opportunities for sustainable horticulture and small-scale ornamental plant enterprises. Previous studies indicate that ornamental NTFPs are often closely linked to forest structural integrity and microclimatic stability, making them sensitive indicators of forest condition (Rambey and Permana 2022; Muis et al. 2023). Their presence in the sub-watershed suggests that portions of the landscape still provide suitable habitats for high-value, forest-dependent ornamental species.

Table 2. Utilization of non-timber forest product (NTFPs) species and their utilized parts in the Sub-watershed of the Mamasa River

Scientific name	Common name	Product category	Utilized part
Persea americana Mill.	Avocado	E	Fruit
Cymbidium dayanum Rchb.f.	Phoenix orchid	F	All plant organs
Phalaenopsis amabilis (L.) Blume	Moon orchid	F	All plant organs
Rhynchostylis retusa (L.) Blume	Foxtail orchid	F	All plant organs
Dendrobium crumenatum Sw.	Pigeon orchid	F	All plant organs
Dendrobium utile J.J.Sm.	Celebes orchid	F	All plant organs
Arenga pinnata (Wurmb) Merr.	Sugar palm	E, N, C	Fruit, sap, branch
Bambusa sp.	Bamboo	E, C	Bamboo shoot, stem
Averrhoa carambola L.	Star fruit	E	Fruit
Averrhoa bilimbi L.	Bilimbi	E	Fruit
Impatiens platypetala Lindl.	Balsam	F	All plant organs
Antidesma bunius (L.) Spreng.	Bignay	E	Fruit
Physalis angulata L.	Cutleaf groundcherry	E	Fruit
Dracontomelon dao (Blanco) Merr. & Rolfe	Dao tree	E	Fruit
Chromolaena odorata (L.) R.M.King & H.Rob.	Siam weed	M	Leaves
Pluchea indica (L.) Less.	Indian camphorweed	M	Leaves
Dillenia serrata Thunb.	Elephant apple	E	Fruit
Durio zibethinus Murray	Durian	E	Fruit
Zingiber officinale Roscoe	Ginger	E	Root/rhizome
Syzygium aqueum (Burm.f.) Alston	Water apple	E	Fruit
Psidium guajava L.	Guava	E	Fruit
Syzygium polyanthum (Wight) Walp.	Indonesian bay leaf	E	Fruit
Syzygium malaccense (L.) Merr. & L.M.Perry	Malay apple	E	Fruit
Anacardium occidentale L.	Cashew	E	Fruit, seed
Auricularia auricula-judae (Bull.) Quél.	Wood ear mushroom	E	All plant organs
Ganoderma lucidum (Curtis) P.Karst.	Reishi mushroom	E	All plant organs
Grifola frondosa (Dicks.) Gray	Maitake mushroom	E	All plant organs
Volvariella volvacea (Bull.) Singer	Straw mushroom	E	All plant organs
Pleurotus ostreatus (Jacq.) P.Kumm.	Oyster mushroom	E	All plant organs
Monstera adansonii Schott	Swiss cheese vine	F	All plant organs
Etlingera elatior (Jack) R.M.Sm.	Torch ginger	E	Root/rhizome
Ficus variegata Blume	Variegated fig	E	Fruit
Theobroma cacao L.	Cacao tree	E	Fruit, seed
Artocarpus altilis (Parkinson) Fosberg	Breadnut	E	Fruit
Gossypium arboreum L.	Tree cotton	C	Fruit (cotton boll)
Schleichera oleosa (Lour.) Oken	Ceylon oak	M	Leaves
Cinnamomum burmannii (Nees & T.Nees) Blume	Indonesian cinnamon	M	Tree bark
Spondias dulcis Parkinson	June plum	E	Fruit
Aleurites moluccanus (L.) Willd.	Candlenut	E	Seed
Coffea canephora Pierre ex A.Froehner	Robusta coffee	E	Fruit, seed
Curcuma longa L.	Turmeric	E	Root/rhizome
Curcuma caesia Roxb.	Black turmeric	E	Root/rhizome
Curcuma zedoaria (Christm.) Roscoe	White turmeric	E	Root/rhizome
Lansium domesticum Corrêa	Langsat	E	Fruit
Dimocarpus longan Lour.	Longan	E	Fruit
Alpinia galanga (L.) Willd.	Greater galangal	E	Root/rhizome
Alpinia purpurata (Vieill.) K.Schum.	Red ginger	E	Root/rhizome
Mangifera sp.	Mango	E	Fruit
Passiflora foetida L.	Stinking passionflower	E	Fruit
Coleus scutellarioides (L.) Benth.	Coleus	M, F	All plant organs
Morus sp.	Mulberry	E	Fruit
Artocarpus heterophyllus Lam.	Jackfruit	E	Fruit
Sticherus flagellaris (Bory ex Willd.) Ching	Forked fern	F	All plant organs
Cyathea arborea (L.) Sm.	Tree fern	F	All plant organs
Asplenium nidus L.	Bird's nest fern	F	All plant organs
Diplazium esculentum (Retz.) Sw.	Vegetable fern	E	Stem and fronds
Pigafetta elata (Mart.) H.Wendl.	Giant mountain palm	F	All plant organs
Caryota mitis Lour.	Fishtail palm	F	All plant organs
Pandanus tectorius Parkinson ex Du Roi	Screw pine	C	Leaves
Pandanus tectorius Parkinson ex Du Roi	Creeping pandan	C	Leaves
Pandanus amaryllifolius Roxb. ex Lindl.	Fragrant pandan	E	Leaves
Areca catechu L.	Betel nut palm	E	Seed
Pinus merkusii Jungh. & de Vriese	Sumatran pine	N	Natural resin

Musa balbisiana Colla	Wild banana	E	Fruit
Aegle marmelos (L.) Corrêa	Bael tree	E	Fruit
Ficus racemosa L.	Cluster fig	E	Fruit
Nephelium lappaceum L.	Rambutan	E	Fruit
Calamus rotang L.	Rattan palm	C	Stem
Cenchrus purpureus (Schumach.) Morrone	Elephant grass	F	All plant organs
Metroxylon sagu Rottb.	Sago palm	E	Stem
Lantana camara L.	Lantana	F	All plant organs
Cymbopogon citratus (DC.) Stapf	Lemongrass	E	Leaves
Dioscorea hispida Dennst.	Bitter yam	M	Leaves
Piper betle L.	Betel leaf	M	Leaves
Annona squamosa L.	Sugar apple	E	Fruit
Rubus sp.	Wild bramble	E	Fruit
Artocarpus altilis (Parkinson) Fosberg	Breadfruit	E	Fruit
Colocasia esculenta (L.) Schott	Taro	E	Root/rhizome
Curcuma zanthorrhiza Roxb.	Java turmeric	E	Root/rhizome
Solanum nigrum L.	Black nightshade	E	Fruit
Vanilla planifolia Andrews	Vanilla	E	Fruit
Tradescantia zebrina Bosse	Inch plant	F	All plant organs
Amorphophallus sp.	Konjac	E	Root/rhizome
Hellenia speciosa (J.Koenig) S.R.Dutta	Crepe ginger	E	Root/rhizome

Note: M: Medicinal and nutraceutical plants, F: Ornamental and flowering plants, N: Natural resins, E: Edible fruits and vegetables, and C: Handicraft materials

Natural resins and handicraft materials, although represented by fewer species, play a strategic role in long-term income generation and cultural continuity. Resin extraction from *P. merkusii* (pine) demonstrates how NTFPs can be harvested without tree felling, thereby maintaining canopy cover and ecosystem functions while providing economically valuable products (Hadiyane et al. 2015). Similarly, handicraft materials derived from *C. rotang* (rattan), *Bambusa* sp. (bamboo), and *P. tectorius* (screw pine) support traditional weaving, furniture production, and local craft industries. These species are commonly associated with secondary forests, riparian zones, and forest-agriculture interfaces, indicating that productive NTFP systems can persist beyond intact forest cores (Desmayanti et al. 2024).

Notably, several species, including *A. pinnata* (sugar palm) and *Coleus scutellarioides*, exhibit multifunctional uses across food, medicinal, and handicraft categories. Such multifunctionality enhances livelihood resilience by allowing households to derive multiple benefits from a limited number of species and reflects functional redundancy within forest-based socio-ecological systems. Similar multifunctional NTFP patterns have been widely reported in tropical landscapes, where diversified resource use reduces dependency on single commodities and increases adaptive capacity (Dyck 2022; Chew et al. 2023).

The utilization-based diversity of non-timber forest products in the Sub-watershed of the Mamasa River has the potential for forest biodiversity to support a range of livelihood, health, and cultural uses. The predominance of edible, medicinal, ornamental, resin, and handicraft NTFPs indicates functional complementarity, with different NTFPs offering subsistence and market-oriented values observed in other tropical forest systems. However, because this study did not collect household-level socio-economic data, these implications should be interpreted as potential rather than measured outcomes. Similar patterns documented in other tropical landscapes showed that diversified NTFP use can reduce dependence on single commodities and may strengthen adaptive capacity under socio-economic and environmental uncertainty (Dyck 2022; Chew et al. 2023). The presence of multifunctional species, such as *A. pinnata* and *C. scutellarioides*, further reflects functional redundancy within forest-based socio-ecological systems, allowing communities to derive multiple benefits from limited species pools. Importantly, this utilization pattern suggests that NTFP use is closely aligned with ecological availability and traditional knowledge systems, reinforcing the role of forests as integrated providers of food security, income diversification, and ecosystem services rather than as residual resource spaces (Latifah et al. 2020; Harianja et al. 2023).

Administrative-based distribution and landscape-level implications of non-timber forest products species

The observed spatial patterns are consistent with potential influences of ecological gradients, hydrological processes, and human land-use practices, although no formal spatial statistical tests were applied (Table 3, Figure 3). These patterns are apparent in the mapped distribution of five taxa, *A. pinnata*, *C. rotang*, *C. arborea*, *P. tectorius*, and *Bambusa* sp., which recorded the highest relative frequency values and occurred repeatedly across multiple sampling clusters and administrative units. The repeated co-occurrence of these species across multiple villages and sub-watershed segments suggests that their distribution is associated with spatial variation in ecological suitability and accessibility at the sub-watershed scale, as reflected in land-cover heterogeneity, topographic context, and proximity to human-modified landscapes. These spatial patterns are interpreted as descriptive and indicative, as no formal spatial statistical tests of randomness or clustering were applied in the present study. *A. pinnata*, which exhibited the highest relative frequency (9.8%), was widely distributed across upland slopes, mid-elevation forests, and settlementadjacent landscapes in 12 villages. This extensive spatial occurrence reflects strong ecological plasticity under both semi-open and moderately shaded conditions, as well as tolerance to variable soil moisture regimes. The spatial clustering of *A. pinnata* in agricultural mosaics and secondary forests suggests a combined influence of natural regeneration and long-term human interaction, particularly selective retention near cultivated areas. These patterns reinforce its role as a keystone livelihood species with high spatial resilience and suitability for landscape-level NTFP development, including sap extraction, fruit harvesting, and fiber use (Azhar et al. 2021).

Rattan (*C. rotang*), with a relative frequency of 7.65%, displayed a wide but more clustered distribution, particularly concentrated within 9 villages. Rattan-rich zones were strongly associated with forest interiors and riparian buffer areas characterized by moderate canopy closure and stable understory conditions. This spatial alignment highlights the species' ecological dependence on sustained soil moisture and structural support from surrounding vegetation. The correspondence between rattan distribution and hydrologically buffered corridors underscores the importance of sub-watershed processes, such as soil moisture retention and periodic flooding, in shaping rattan assemblages and regeneration dynamics (Thonhofer et al. 2015; Rozali et al. 2021).

Cyathea arborea (RF: 5.36%) exhibited high frequency within mid-elevation moist forest patches, particularly in 12 villages. Its presence across multiple topographic gradients reflects the persistence of mesic microhabitats, especially in degraded but recovering secondary forest. The mapping output shows a clear clustering of *C. arborea* along slope breaks and valley bottoms (Figure 3), indicating that microsite stability and humidity are key determinants of spatial occupancy (Sosanika et al. 2022).

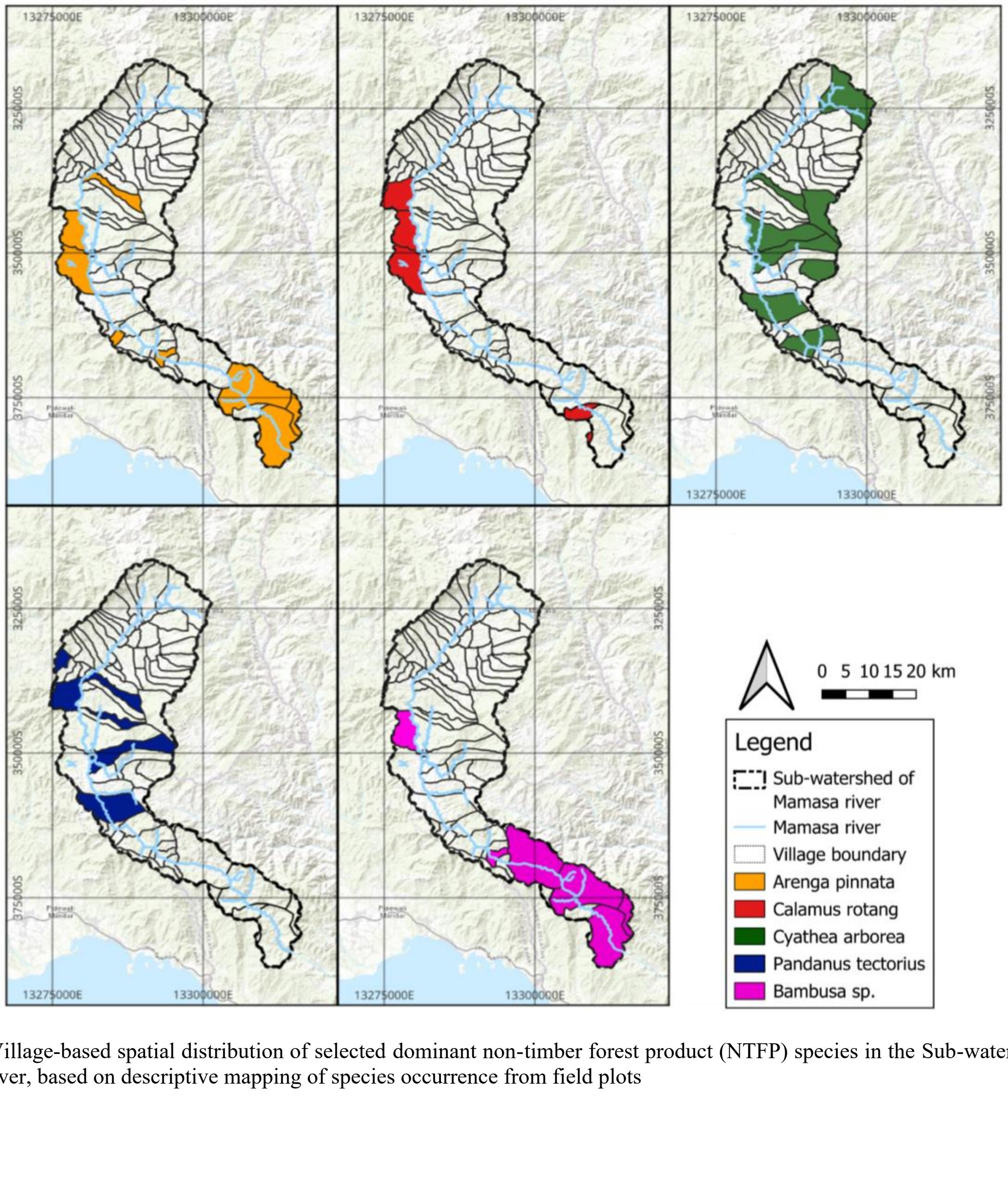

Figure 3. Village-based spatial distribution of selected dominant non-timber forest product (NTFP) species in the Sub-watershed of the Mamasa River, based on descriptive mapping of species occurrence from field plots

Table 3. Village-level occurrence and habitat characteristics of the five dominant NTFP species in the sub-watershed of the Mamasa River

Species	Villages where present	Dominant habitat and landscape characteristics
Arenga pinnata (Wurmb) Merr.	Basseang, Lembang Mesakada, Ulu Saddang, Katimbang, Kurrak, Makuang, Malabo, Mambu Tapua, Salubalo, Sasakan, Tanete Batu, Tapua	Widely distributed across semi-open to moderately shaded environments; occurs from upland to mid-elevation areas; tolerant of varied light conditions; commonly associated with agricultural mosaics and secondary forests; indicative of high ecological plasticity and strong regeneration capacity.
Calamus rotang L.	Betteng, Katimbang, Kurrak, Mambu Tapua, Minake, Salubalo, Sasakan, Tapua, Ulumambi Barat	Clustered distribution mainly in forest interiors and riparian buffer zones; associated with intact understory cover and moderate canopy closure; strongly influenced by soil moisture availability and hydrological stability; commonly forms corridors along streams and valleys.
Cyathea arborea (L.) Sm.	Batangnguru Timur, Kanan, Lambanan, Malabo, Malangkena Padang, Matande, Passembuk, Rante Kamase, Rippung, Saloan, Tadisi, Tadokalua	Concentrated in mid-elevation moist forest patches; frequently found along slope breaks and valley bottoms; associated with mesic microhabitats in degraded but regenerating secondary forests; sensitive to microclimatic stability and humidity.
Pandanus tectorius Parkinson ex Du Roi	Batupapan, Malabo, Mannababa, Minake, Rippung, Saloan, Tadisi, Ulumambi Barat	Predominantly associated with anthropogenic edges and forest–agriculture interfaces; favors partial sunlight and periodically disturbed soils; forms linear patches along transitional zones; exhibits high tolerance to human-modified landscapes.
Bambusa sp.	Basseang, Lembang Mesakada, Suppiran, Ulu Saddang, Mambu Tapua, Salubalo, Tanete Batu, Tapua	Primarily distributed in lowland valleys and wetter areas; associated with high soil moisture and periodic flooding; forms dense stands in flood-prone zones; closely linked to long-term community use and informal domestication.

In contrast, *P. tectorius* (RF 4.9%) and *Bambusa* sp. (RF 4.44%) exhibited spatial patterns closely linked to anthropogenic edges and valley bottoms, respectively. *P. tectorius* was frequently observed near settlements and along forest–agriculture interfaces across 8 villages, forming linear patches that reflect both ecological resilience to disturbance and facilitation by human land-use practices. Its preference for partial sunlight and periodically disturbed soils highlights its suitability for community-based harvesting and edge-oriented management strategies (Prasaja 2019). Meanwhile, bamboo clusters were concentrated in wetter lowland valleys and flood-prone areas across 8 villages, where high soil moisture and periodic inundation promote dense stand formation. These patterns align with the species' long history of local utilization and informal domestication, reinforcing the link between hydrological regimes, land-use history, and bamboo persistence (Damayanto and Rahmawati 2020).

Collectively, the spatial distribution of these high-frequency NTFP species reflects a heterogeneous landscape mosaic, with dominant taxa occurring across different landscape elements. Rather than being confined to intact forest cores, many economically valuable NTFPs are observed in secondary forests, riparian corridors, and agroforestry-adjacent zones. This spatial heterogeneity suggests the potential for ecosystem services and livelihood opportunities to be distributed across multiple landscape elements within the sub-watershed. Importantly, the observed distribution pattern of *A. pinnata*, *C. rotang*, *Bambusa* sp., *C. arborea*, and *P. tectorius* suggests potential entry points for spatially explicit NTFP management, including village-level zoning, riparian buffer enrichment, and targeted restoration of degraded sub-watershed units. When integrated into sustainable landscape planning, these species can simultaneously support local economies and reinforce conservation objectives across the sub-watershed (Chew et al. 2023; Desmayanti et al. 2024).

The coexistence of widely distributed, disturbance-tolerant species such as *A. pinnata* and *P. tectorius* with habitat-specific taxa such as *C. rotang* and *C. arborea* reveals a landscape in which different ecological niches are maintained across secondary forests, riparian buffers, valley systems, and agroforestry interfaces. This pattern indicates that the sub-watershed retains sufficient environmental heterogeneity to support both regeneration-dependent and human-facilitated NTFPs, thereby sustaining livelihood-relevant resources across multiple spatial contexts. Importantly, the alignment between species-specific habitat preferences and village-level occurrence highlights the potential of spatially explicit NTFP management approaches that integrate ecological suitability with local accessibility. As such, the observed spatial configuration provides a robust empirical basis for linking biodiversity conservation with community-based resource utilization, reinforcing the role of NTFPs as functional connectors between landscape structure, ecosystem services, and rural livelihoods at the sub-watershed scale (Chew et al. 2023; Desmayanti et al. 2024).

In conclusion, this study identified 84 Non-Timber Forest Product (NTFP) species in the Sub-watershed of the Mamasa River and quantified their structural patterns, revealing that *Pinus merkusii* is the most dominant species, while *Arenga pinnata* exhibits the widest spatial distribution; other ecologically important species include *Cyanthea arborea*, *Calamus rotang*, and *Diplazium esculentum*. The findings further highlight utilization-based diversity, where resin-producing trees, palms, rattans, and edible understory species demonstrate that NTFPs provide multiple ecological and livelihood functions. Spatial analysis indicates that NTFPs are unevenly distributed, with higher concentrations in secondary forests, riparian zones, and forest-agriculture interfaces, underscoring their importance in landscape-level management. Based on these findings, NTFP management should be systematically integrated into sub-watershed planning by prioritizing high-value and widely distributed species such as *Arenga pinnata*, *Calamus rotang*, and *Diplazium esculentum*, supported through the establishment of village-level development zones, the implementation of sustainable harvesting practices, and community-based management approaches; additionally, spatially explicit distribution maps should be utilized to guide restoration and management, particularly in riparian and other critical areas, alongside targeted capacity-building efforts to ensure long-term ecological integrity and socio-economic sustainability.

REFERENCES

Ajay A, Kumar MR, Badhusha PAS, Gowda SK, Ramesh B. 2021. Pharmacological importance of *Chromolaena odorata*: A review. Intl J Pharm Drug Anal 9 (1): 8-11. https://doi.org/10.47957/ijpda.v9i1.452.

Anita D, Musyafa M, Widyastuti SM. 2022. The potency of honey bee forage on beekeeping of *Apis cerana* F. In Wanagama Education Forest, Gunungkidul, Yogyakarta. Jurnal Ilmu Kehutanan 16 (2): 198-208. https://doi.org/10.22146/jik.v16i2.1738.

Archibold OW. 1995. The Tropical Forests. In: Ecology of World Vegetation. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-0009-0_2.

Azhar I, Nasution Z, Delvian, Agussabti, Aulin FR, Sembiring MR. 2021. Utilization of sugar palm (*Arenga pinnata* Merr.) By communities around PT Toba Pulp Lestari. IOP Conf Ser: Earth Environ Sci 782: 032017. https://doi.org/10.1088/1755-1315/782/3/032017.

Borma LD. 2023. Why Tropical Forests Are Important for Our Well-Being. Eos Transactions American Geophysical Union 104. https://doi.org/10.1029/2023EO235005.

Brancalion PHS, Niamir A, Broadbent E, Crouzeilles R, Barros FSM, Almeyda Zambrano AM, Baccini A, Aronson J, Goetz S, Reid JL, Strassburg BBN, Wilson S, Chazdon RL. 2019. Global restoration opportunities in tropical rainforest landscapes. Sci Adv 5 (7): eaav3223. https://doi.org/10.1126/sciadv.aav3223.

Budiharta S, Holl KD. 2025. Harnessing opportunities to upscale forest landscape restoration in Indonesia. Trees For People 21: 100917. https://doi.org/10.1016/j.tfp.2025.100917.

Chew WC, Okuda T, Mon SM, Mandal MSH, Shigematsu C, Shin T, Thant AM. 2023. Spatial and temporal analysis of commercialized NTFP production in Myanmar. Tropics 31 (4): 95-109. https://doi.org/10.3759/tropics.SINT03.

Curtis JT, McIntosh RP. 1951. An upland forest continuum in the Prairie-Forest Border Region of Wisconsin. Ecology 32: 476-496. http://dx.doi.org/10.2307/1931725.

Damayanto IPGP, Rahmawati K. 2020. Bamboo diversity in Banggai Kepulauan, Central Sulawesi, Indonesia. Jurnal Biodjati 5 (1): 1-14. https://doi.org/10.15575/biodjati.v5i1.6230.

Desmayanti R, Kardiman R, Anhar A, Violita V. 2024. Non-timber forest products used as commercialized crafts in Padang Panjang City, West Sumatra. Jurnal Biologi Tropis 24 (2): 1-8. https://doi.org/10.29303/jbt.v24i2.6699.

Dyck M. 2022. Non-Timber Forest Problems: NTFPs in Conservation and Development Initiatives. In: Tropical Forest Ecosystem Services in Improving Livelihoods for Local Communities. Springer Nature Singapore, Singapore. https://doi.org/10.1007/978-981-19-3342-4_3.

Elias JP, e Silva BA, de Carvalho RG, Sampaio MB, Mendieta-Leiva G, Ramos FN. 2024. Tree structure instead of microclimatic zones determines differences in vascular epiphyte assemblages. For Ecol Manage 552: 121567. https://doi.org/10.1016/j.foreco.2023.121567.

Flotemersch JE, Leibowitz SG, Hill RA, Stoddard JL, Thoms MC, Tharme RE. 2016. A watershed integrity definition and assessment approach. River Res Appl 32 (7): 1654-1671. https://doi.org/10.1002/rra.2978.

Ghorbani A, Langenberger G, Liu JX, Wehner S, Sauerborn J. 2012. Diversity of medicinal and food plants as non-timber forest products in Naban River Watershed National Nature Reserve (China): implications for livelihood improvement and biodiversity conservation. Econ Bot 66 (2): 178-191. https://doi.org/10.1007/s12231-012-9188-1.

Gyeltshen T, Bhatta CP, Gurung T, Dorji P, Tenzin J. 2024. Ethnomedicinal uses and cultural importance of stingless bees in Bhutan. J Ethnobiol Ethnomed 20 (1): 42. https://doi.org/10.1186/s13002-023-00639-8.

Hadiyane A, Sulistyawati E, Dungani R. 2015. A study on production of resin from *Pinus merkusii* Jungh. Et De Vriese in the Bosscha Observatory Area, West Java-Indonesia. Asian J Plant Sci 14 (2): 89-93. https://doi.org/10.3923/ajps.2015.89.93.

Harianja AH, Adalina Y, Pasaribu G, Winarni I, Maharani R, Fernandes A, Saragih GS, Fauzi R, Tampubolon AP, Njurumana GN, Sukito A. 2023. Potential of beekeeping to support livelihoods in Indonesia. Forests 14 (2): 321. https://doi.org/10.3390/f14020321.

Hartiningtias D, Fulé PZ, Gunawan AA. 2020. Wildfire effects on *Pinus merkusii* forest structure. For Ecol Manag 457: 117660. https://doi.org/10.1016/j.foreco.2019.117660.

Hoggarth DD, Thomas MA, Sarnita AS, Ondara O. 1998. Spatial co-management of Indonesian floodplain fisheries. Indones Fish Res 4 (1): 23-31. http://dx.doi.org/10.15578/ifrj.4.1.1998.23-31.

Jiang Y, Chen Z, Lin H, Deng R, Liang Z, Li Y, Liang S. 2024. Trait-based community assembly across subtropical karst forests. Front Plant Sci 15: 1451981. https://doi.org/10.3389/fpls.2024.1451981.

Kumari N, Prakash S, Sharma N, Puri S, Thakur M, Singh J, Kumar M. 2024. Medicinal and aromatic plants as potential sources of bioactives along with health-promoting activities. Curr Food Sci Technol Rep 2 (4): 359-376. https://doi.org/10.1007/s43555-024-00042-8.

Latifah S, Lubis NA, Fachrudin KA, Purwoko A. 2020. Contribution of ntfps to household income in South Tapanuli. J Phys Conf Ser 1542: 012035. https://doi.org/10.1088/1742-6596/1542/1/012035.

Li Y, He JA, Yu S, Wang H, Ye S. 2020. Spatial structures of different-sized tree species in a secondary forest in the early succession stage. Eur J For Res 139 (5): 709-719. https://doi.org/10.1007/S10342-020-01280-W.

Mueller-Dombois D, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons, New York. https://doi.org/10.2307/213332.

Muis A, Hiola FSI, Syamsiah, Khatima H. 2023. Inventory of domesticated orchid species in Samaenre Village, Mallawa District, Maros Regency, South Sulawesi, Indonesia. IOP Conf Ser: Earth Environ Sci 1209: 012021. https://doi.org/10.1088/1755-1315/1209/1/012021.

Pacheco FAL, Fernandes LFS. 2020. Watersheds, anthropogenic activities and the role of adaptation to environmental impacts. Water 12 (12): 3451. https://doi.org/10.3390/w12123451.

Pandiangan DC, Supriana T, Nuryawan A. 2023. Contribution of non-wood forest product utilization to household income in North Tapanuli Regency, North Sumatra, Indonesia. J Sylva Indonesiana 6 (2). https://doi.org/10.32734/jsi.v6i02.10236.

Permatasari A, Mosa SA, Winata B, Rusniarsyah L, Peniwidiyanti P, Izzbilhaq I. 2024. Tree species diversity and management in agroforestry pohpohan (*Pilea melastomoides*): The case in the traditional zone of Gunung Halimun Salak National Park, Indonesia. Biotropia 31 (3): 380-390. https://doi.org/10.11598/btb.2024.31.3.2281.

Poorter L, Craven D, Jakovac CC, van der Sande MT, Amissah L, Bongers F, Chazdon RL, Farrior CE, Kambach S, Meave JA, Muñoz R, Norden N, Rüger N, van Breugel M, Almeyda Zambrano AM, Amani B, Andrade JL, Brancalion PHS, Broadbent EN, de Foresta H, et al. 2021. Multidimensional tropical forest recovery. Science 374 (6573): 1370-1376. https://doi.org/10.1126/science.abh3629.

Prasaja D. 2019. Floristic composition, distribution, and association of Pandanus (Pandanaceae) in Bukit Duabelas National Park, Jambi. Jurnal Biologi 12 (1): 1-13. https://doi.org/10.20414/jb.v12i1.165.

Rambey R, Permana J. 2022. Identification of ornamental plant species in the Martelu Purba Nature Reserve, North Sumatra. IOP Conf Ser: Earth Environ Sci 1115: 012024. https://doi.org/10.1088/1755-1315/1115/1/012024.

Robles-Diaz-de-Leon LF, Kangas P. 1998. Evaluation of potential gross income from non-timber products in a model riparian forest for the chesapeake bay watershed. Agroforestry Systems 44 (2): 215-225. https://doi.org/10.1023/A:1006246510419.

Rohani S, Lee FL, Yusoff AS. 2020. Diversity and vertical distribution of vascular epiphytes on a Malaysian mangrove island. Biotropia 27 (2). https://doi.org/10.11598/btb.2020.27.2.1182.

Rozali FZ, Masum KM, Mansor MS, Mansor A. 2021. Rattan composition and diversity in tropical rainforests of Peninsular Malaysia. Biodivers Conserv 30: 3475-3493. https://doi.org/10.1007/s10531-021-02226-3.

Scholten T, Seitz S. 2019. Soil erosion and land degradation. Soil Syst 3 (4): 68. https://doi.org/10.3390/soilsystems3040068.

Singh GS. 1999. Utility of non-timber forest products in a small watershed in the Indian Himalayas: the threat of its degradation. Nat Resour Forum 23 (1): 65-77. https://doi.org/10.1111/j.1477-8947.1999.tb00239.x.

Soma AS, Chaeruddin AA, Wahyuni. 2023. Analysis of the quality of the Mamasa sub-watershed using the land cover approach and land cover projections in 2031. IOP Conf Ser: Earth Environ Sci 1277: 012023. https://doi.org/10.1088/1755-1315/1277/1/012023.

Sosanika GL, Sule B, Fazang K, Homot P, Kaina G, Kiapranis R, Damas K, Hitofumi A, Turia R, Testolin R, Attore F. 2022. Fern species richness and diversity in forest ecosystems of Papua New Guinea. Case Stud Environ 6 (1): 1696511. https://doi.org/10.1525/cse.2022.1696511.

Springgay E. 2017. Headwater Catchments: Foundation Pillars for Ecosystem Services. In: Ecosystem Services from Forest Landscapes. Springer. https://doi.org/10.1007/978-3-319-57946-7_1.

Sulistyawati E, Nasution T, Rosleine D, Putra DC. 2018. Tree community structure and composition of a one-hectare permanent plot in Mount Kerinci. J Math Fundam Sci 50 (3): 315-331. https://doi.org/10.5614/j.math.fund.sci.2018.50.3.7.

Supartono T, Adhya I, Hendrayana Y, Kosasih D, Dahrun, I. 2022. Tree species growing on *Pinus merkusii* stands at Karangsari Research Station, Gunung Ciremai National Park, West Java. In UNISET 2021: Proceedings of the 2nd Universitas Kuningan International Conference on System, Engineering, and Technology, UNISET 2021, 2 December 2021, Kuningan, West Java, Indonesia. European Alliance for Innovation.

Thonhofer J, Getto D, van Straaten O, Cicuzza D, Kessler M. 2015. Influence of spatial and environmental variables on rattan palm assemblages in Central Sulawesi. Plant Ecol. https://doi.org/10.1007/s11258-014-0416-x.

Tlau L, Lalawmpuii L. 2020. Commonly used medicinal plants in Mualcheng, Mizoram, India. Sci Vis 20 (4): 156-161. https://doi.org/10.33493/scivis.20.04.03.

Trouvé R, Nitschke CR, Andrieux L, Willersdorf T, Robinson AP, Baker PJ. 2019. Competition drives decline of a dominant midstorey tree species. For Ecol Manag 447: 26-34. https://doi.org/10.1016/j.foreco.2019.05.055.

Ulyshen MD, Urban-Mead KR, Dorey JB, Rivers JW. 2023. Forests are critically important to global pollinator diversity. Biol Rev 98 (3). https://doi.org/10.1111/brv.12947.

Wierzcholska S, Dyderski MK, Jagodziński AM. 2020. Potential distribution of an epiphytic bryophyte depends on climate and forest continuity. Glob Planet Change 193: 103270. https://doi.org/10.1016/j.gloplacha.2020.103270.