

Utilization of biological resources and its challenges for environmental sustainability on the slopes of Mount Merbabu, Central Java, Indonesia

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Abstract. *Ayuningtyas HR, Azizah HPN, Nabila I, Izdihar RS, Setyawan AD. 2025. Utilization of biological resources and its challenges for environmental sustainability on the slopes of Mount Merbabu, Central Java, Indonesia. Asian J Environ 1: 70-85.* Biological natural resources are biological elements in nature and consist of flora and fauna resources that form an ecosystem. Biological resources of flora and fauna benefit people's lives as a source of food, clothing, medicine, and other necessities of life. The utilization of biological resources by Indonesian people illustrates the bond between people and their environment, including relationships related to local traditions and culture. The diversity of biological resources in a region can affect the culture and economy of the area. This research was conducted on the eastern slopes of Mount Merbabu, with a case study of Ngangrong Village, Candisari Village, and Ngargoloka Village, Gladagsari District, Boyolali District. This research aims to identify the local village's biological resources and assess the sustainable utilization by residents in their cultural and economic needs. The methods used in this research are surveys, group discussions, and informant interviews. There were 68 informants, and 8 of them were key informants. The results showed that the local community utilizes 47 species of flora and 12 species of fauna. The utilization of biological resources on the eastern slopes of Mount Merbabu reveals key trends in flora and fauna over the period from 2017 to 2023. A total of 47 species of flora were identified, with fruit plants making up the largest portion at 34%, for fauna, a total of 12 species were found, with mammals representing 50% of the fauna resources.. Local people mainly utilize fauna biological resources as the head source of income. Meanwhile, people are more likely to use fauna biological resources for personal consumption.

Keywords: Biological resources, Mount Merbabu, sustainable utilization

INTRODUCTION

Natural resources are resources derived from the environment that support life. The diversity of biological natural resources in terms of their types, numbers, and uniqueness enhances life support systems, providing essential services such as food, medicine, and material for cultural practices (Riyadi et al. 2023). For sustainable resource utilization, effective management and processing are needed (Cetinkaya et al. 2014), to ensure the preservation of Earth's equilibrium, especially in the context of increasing pressures from economic growth and population expansion (Nassani et al. 2021). Natural resources provide livelihoods to millions in developing countries, where overexploitation often occurs without regard for sustainability (Maja and Ayano 2021). Indonesia, rich in natural resources, provides a prime example of both the abundance and challenges of managing these resources sustainably (Sarwono and Kusumanto 2021). The biological diversity in Indonesia, including diverse flora and fauna, plays a crucial role in local economies, cultures, and ecosystems (Nonic and Sijajic-Nikolic 2021). Biodiversity supports various sectors of the economy, especially in rural areas where communities rely on these resources for subsistence and income generation (Surya et al. 2020).

However, current economic development and population growth in Indonesia are placing unsustainable demands on biological resources, leading to overuse and environmental degradation (Jhariya et al. 2022). The lack of proper knowledge and awareness of resource management practices contributes to suboptimal utilization, further exacerbating these issues. Using natural resources to meet human consumption needs often leads to land-use changes, making regions more vulnerable to environmental stresses such as deforestation and loss of biodiversity (Zahoor et al. 2022). To address these challenges, wise management practices are essential to balance human needs and environmental sustainability, particularly in areas where biodiversity is high but threatened by unsustainable practices (Duadji et al. 2023).

The role of law in regulating natural resource utilization is also critical in ensuring sustainability, particularly in preventing exploitation by powerful entities that may undermine environmental protection efforts (Li et al. 2019). For instance, in UUD RI (*Undang-Undang Dasar Republik Indonesia*) 1945 33 (3) plays a central role in managing the country's natural resources by ensuring that they are used for the benefit of the people and the environment (Djayaputra 2021). Effective policy frameworks and community-driven conservation efforts are

crucial in improving environmental quality and fostering long-term welfare (Syahza et al. 2020).

Biological resources have multifaceted benefits for human life, impacting not only economic sectors but also the social and cultural fabric of communities (Regier 2020). The health of a region's economy is often linked to the sustainable use of biological resources, as they are integral to agricultural practices, livelihood strategies, and community culture (Mossberger et al. 2022). In mountain communities, such as those surrounding Mount Merbabu, Central Java, Indonesia land-use activities are heavily influenced by the availability of biological resources. This reliance on biodiversity often dictates both agricultural and livestock-based livelihoods (Ramakrishnan 2003).

Mount Merbabu, a rich biodiversity hotspot, is home to 135 species of flora, including 35 species of trees, 100 species of undergrowth, 60 species of medicinal plants, and 57 ornamental species. Additionally, the mountain supports a rich array of fauna, including primates, herpetofauna, aves, butterflies, and mammals (Balai Taman Nasional Gunung Merbabu 2019). The unique climatic factors sunlight and rainfall create an environment conducive to the growth of diverse plant species, further supporting the region's rich biodiversity (Rahayuningsih et al. 2021). Understanding how these resources are utilized and conserved by local communities is essential to ensuring that the benefits of biodiversity are sustained in the face of increasing demand for land and resources. This research aims to identify the local village's biological resources and examine how residents utilize these resources to meet their cultural and economic needs in the context of the eastern slopes of Mount Merbabu.

MATERIALS AND METHODS

Research area

Mount Merbabu National Park is administratively located in Boyolali District, Magelang District, and Semarang District in Central Java. This research was conducted on the eastern slopes of Mount Merbabu, which has an altitude of ± 600 -3,142 meters above sea level (Balai Taman Nasional Gunung Merbabu 2020), precisely in Ngagrong, Candisari, and Ngargoloka Villages, located in Gladagsari Sub-district, Boyolali District, Central Java (Figure 1). This area was selected for its rich biodiversity and its significant role in supporting the livelihoods of local communities, whose economic activities are heavily dependent on the sustainable use of the region's biological resources.

Geographically, Ngagrong Village lies between $7^{\circ}27'28.5''$ S and $110^{\circ}29'42.0''$ E, Candisari Village lies between $7^{\circ}27'26.6''$ S and $110^{\circ}29'47.1''$ E, and Ngargoloka Village lies between $7^{\circ}26'39.3''$ S and $110^{\circ}29'38.8''$ E. The eastern slope of the Merbabu area is included in the type B volcanic area with a tropical climate, which affects the geological cycle of its constituents, influencing land productivity and biodiversity. This volcanic region is particularly prone to natural disturbances such as erosion and landslides, which can impact the sustainability of local farming and conservation efforts (Sémah et al. 2021).

Meanwhile, the overall temperature in Boyolali District ranges from 27 - 30°C (Noor et al. 2023). In all three villages, the utilized area is dominated by agriculture, particularly crops such as tobacco, vegetables, and fruits, followed by animal husbandry, including cattle, goats, and poultry (Ramadhanty 2019). These activities form the primary source of livelihood for the local communities, which are highly dependent on the availability and sustainability of biological resources.

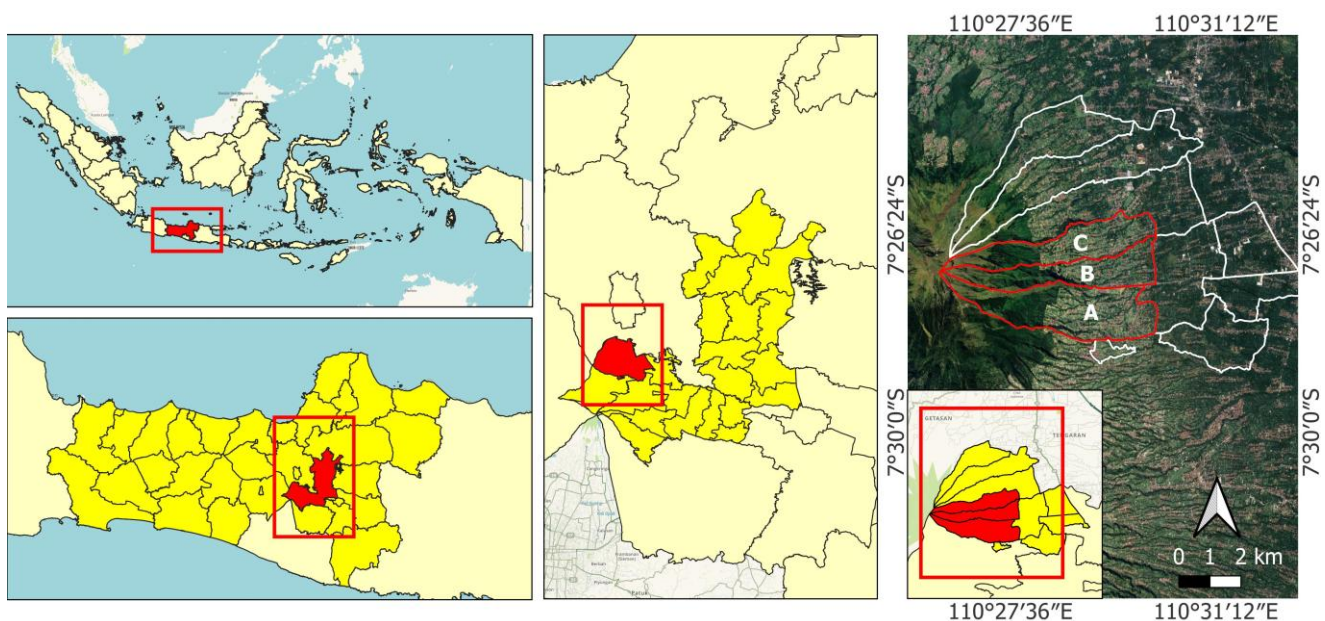


Figure 1. Research locations in A. Ngagrong, B. Candisari, and C. Ngargoloka Villages, Gladagsari Sub-district, Boyolali District, Central Java, Indonesia

Data collection

This study employed a mixed-methods approach, combining semi-structured interviews, observation, and ethnographic fieldwork to gather comprehensive data from local communities. Purposive sampling was used to select 68 informants, including farmers, village leaders, livestock keepers, and other key stakeholders, ensuring a diverse representation of socio-economic backgrounds. This allowed for a comprehensive understanding of local practices in resource utilization and sustainability. Samples were taken randomly to represent the community's diversity with informants' diverse demographic backgrounds and data on the use of biological resources for each informant (Beltrán-Rodríguez et al. 2014).

Data on the availability and use of floral and faunal biological resources for the period 2017-2022 were obtained from secondary sources, including village records, local government statistics, and relevant documents from the Mount Merbabu National Park and other local institutions. In contrast, the current data for 2023 were collected as primary data through interviews, observation, and ethnographic fieldwork in Ngagrong, Candisari, and Ngargoloka Villages. A total of 68 community members and 8 key informants were selected using purposive sampling based on their knowledge and involvement in the use of biological resources. Interviews explored species used, purposes of use (subsistence, income, cultural practices), perceived changes in availability, and local management practices, while direct observation and ethnographic notes documented land-use patterns and on-site resource utilization.

Primary data

Interviews were conducted with 68 villagers, representing a range of socio-economic groups. These included subsistence farmers, small-scale livestock keepers, and local traders. The diversity in socio-economic status allows for an understanding of how economic pressures, land access, and cultural practices influence the use and management of biological resources. According to Ahmadzai et al. (2021), individuals' access to resources, such as land or market access, often determines their level of engagement with sustainable resource practices, with wealthier individuals or those with larger landholdings typically having more access to modern agricultural techniques and markets.

Structured interviews were carried out using a combination of open-ended and closed-ended questions, designed to capture both quantitative and qualitative data. The questionnaire focused on the types of biological resources available in the region, their cultural significance, and how local residents utilize these resources for both subsistence and economic purposes. Interviews also included questions on the challenges they face in utilizing resources sustainably, linking the individuals' economic constraints to their sustainability practices. Research by Ali et al. (2025a) highlights that socio-economic pressures such as poverty often limit the ability of local communities to implement sustainable practices, as immediate economic needs often take precedence.

Key informant interviews were conducted with 8 key individuals, including the village heads from Ngagrong, Candisari, and Ngargoloka Villages, as well as five local community leaders. These individuals were selected because of their influence within the community and their extensive knowledge of biological resource use and cultural practices. The interviews were conducted using a semi-structured questionnaire, which focused on the types of biological resources, historical trends in resource use, and community perceptions of sustainability. This method allowed for a detailed understanding of the socio-political context of resource management, which is critical for analyzing the broader implications of resource use patterns. Schlunegger et al. (2024) stated that data from these interviews were cross-checked with secondary data sources and triangulated with observations to ensure the reliability of the findings.

Secondary data

These secondary data were used to reconstruct temporal patterns in the availability of key biological resources on the eastern slopes of Mount Merbabu. Secondary data was collected from Central Bureau of Statistics/*Badan Pusat Statistik* (BPS) of Gladagsari Sub-district, including information on population demographics and land-use patterns from 2017 to 2023. This data provided broader context on how socio-economic trends, such as migration, urbanization, and land fragmentation, affect local resource utilization practices. Studies indicate that such socio-economic trends are increasingly influencing how communities interact with their natural environment, leading to changing resource management practices (Jehan et al. 2023).

RESULTS AND DISCUSSION

Demographic data of the respondents

Mount Merbabu, located in Central Java, Indonesia is not only a biodiversity hotspot but also an area where local culture and traditions are intricately tied to the surrounding natural environment. The community's deep connection with biological resources including flora, fauna, and natural landscapes is not just an economic necessity but also a cultural imperative. The demographic characteristics revealed in Table 1 provide important insights into how the social and economic structure of the community influences both the utilization of biological resources and the traditional knowledge surrounding them.

Gender

The community around Mount Merbabu is predominantly agriculture-based, and gender roles within this context often shape how biological resources are used and managed. While the gender distribution in the study is almost equal, traditional roles may still influence who participates in what activities. Women are often more involved in home gardening, gathering medicinal plants, and small-scale farming practices, while men typically engage in livestock management and commercial

agriculture. This division of labor also affects knowledge transfer. Sood et al. (2016) stated that women may have more extensive knowledge of medicinal plants or domestic resources used for food and health, while men often have a greater understanding of livestock management and large-scale crop production. Both genders contribute crucial knowledge, which can support sustainable resource management if integrated effectively.

Age

The age distribution of the respondents shows a strong representation of individuals between 26 to 65 years old (67.76% of respondents). This is the age group that holds the most responsibility in terms of resource management, as they are typically the main participants in agriculture and livestock farming, which are key to the survival and economy of the community. In many rural areas like those around Mount Merbabu, older generations tend to hold more traditional ecological knowledge such as understanding the seasonal cycles, resource management practices, and sustainable agricultural methods. These practices are often passed down through generations and form an essential part of the community's cultural heritage (Okui et al. 2021).

For instance, in the villages around Mount Merbabu, it is common for elderly farmers to teach younger generations about traditional planting techniques, the use of medicinal plants, and methods of sustainable farming. This knowledge is deeply tied to the cultural practices of the community, and many younger individuals view these practices not only as practical skills but also as important cultural rituals that help maintain environmental harmony.

However, the younger generation (ages 15-25 years old) is increasingly exposed to modern agricultural methods that prioritize economic gain and technological advancement over traditional practices. This shift can sometimes create a disconnect between generational knowledge and contemporary approaches, leading to changes in how biological resources are utilized and managed. For example, younger farmers may adopt more intensive cash crop farming, focusing on crops like tobacco or vegetables, which are highly marketable, but may not always consider long-term sustainability.

Profession

The fact that 76.47% of the respondents are farmers highlights the significance of agriculture in the daily lives of the Mount Merbabu community. Agricultural activities which include the cultivation of crops, management of livestock, and use of medicinal plants are deeply intertwined with the social fabric of rural life. In these communities, the practice of farming is often passed down through families, and it is not just a means of earning a living but also a way of maintaining cultural continuity.

For example, in Ngagrong, Candisari, and Ngargoloka Villages, the cultivation of tobacco and other crops is not only an economic activity but also an important cultural tradition. Communities hold rituals around the planting and harvesting seasons, marking these events as part of their communal life. The knowledge of land management and the sustainable use of resources is embedded in these cultural practices, making farming not just about profit but also about identity and heritage.

However, the focus on market-driven agriculture can also bring challenges. As agricultural markets become more competitive and farmers become more reliant on high-yield crops for income, the cultural value of sustainable farming practices might take a back seat to commercialization. This tension between traditional practices and modern economic pressures is a key issue for the community around Mount Merbabu, as the local economy depends heavily on agriculture, but is also threatened by unsustainable land-use practices (Jehan et al. 2023).

Education

The low levels of formal education (with 60.29% of respondents having completed only elementary school) indicate that traditional ecological knowledge plays a significant role in the community's relationship with the environment. Farmers and local villagers, despite limited formal schooling, often have deep ecological insights based on years of direct interaction with the land. This knowledge is often passed down verbally and is critical for managing local biodiversity.

In many cultures, including those around Mount Merbabu, cultural norms emphasize the importance of knowledge transfer through elders, who serve as the primary bearers of traditional knowledge (Ali et al. 2022). This knowledge includes not only how to utilize biological resources sustainably but also how to respect and preserve them as part of the community's identity.

Table 1. Demographic data of the respondents

Parameter	Specification	Freq.	Percentage
Gender	Male	33	48.53
	Female	35	51.47
Age	15-25	4	5.88
	26-35	16	23.53
	36-45	11	16.18
	46-55	13	19.12
	56-65	16	23.53
	66+	8	11.76
Profession	Farmer	52	76.47
	Merchant	1	1.47
	Entrepreneur	2	2.94
	Laborer	8	11.76
	Civil Servant	3	4.41
	Random	2	2.94
Education	Elementary School	41	60.29
	Junior High School	4	5.88
	Senior High School	20	29.41
	University	3	4.41

However, the education gap also presents challenges. While older generations may have an extensive understanding of local resources, younger generations especially those with higher education levels (4.41% having attended university) might lack the same hands-on knowledge of sustainable practices. Therefore, bridging the gap between traditional ecological knowledge and modern scientific approaches is vital for creating holistic management practices for sustainable resource use (Rani et al. 2025).

Flora as biological resources on the eastern slopes of Mount Merbabu

The data shows significant fluctuations in the availability of certain plant species over the years, from 2017 to 2023. Notably, some species have remained consistently available, while others have seen increases or decreases in their presence (Table 2 and Figure 2). In the period from 2017 to 2019, only 26% of flora species were classified as green mark, meaning they were readily accessible and easily obtainable for both personal use and income generation. By 2021-2022, this proportion increased to 77%, suggesting that more species have become available due to improved cultivation practices or increased market demand. This could also indicate that high-value species, such as fruit plants (*Mangifera indica* L., *Durio zibethinus* Murray) and timber species (*Tectona grandis* L.f.), have been successfully incorporated into commercial farming systems, increasing their accessibility.

However, the percentage of species in the yellow category (those still readily available but becoming more limited) has steadily declined from 49% in 2017-2019 to 21% in 2023. This suggests that certain species, previously abundant and easily accessible, are now facing increased pressure, potentially due to overuse, land-use changes, or market expansion. Species such as medicinal plants (*Curcuma longa* L.) and fruit crops (*Citrus × aurantium*

L.) are now less accessible, possibly because they are over-exploited for both local consumption and commercial trade, with limited availability leading to scarcity.

The most concerning trend is the rise of species classified as red category species (difficult to locate), which accounted for 26% of species in 2017-2019 but saw a sharp decline to 0% by 2021-2022, before dramatically increasing to 100% in 2023. This shift indicates that several species, once common or accessible, have now become extremely scarce or nearly extinct in the region. The drastic increase in red category species suggests that factors such as habitat destruction, overharvesting, and climate change are having a severe impact on the flora of Mount Merbabu. These species are no longer viable for local use, either due to the loss of natural habitats or climatic shifts affecting their growth and reproduction.

These trends highlight significant sustainability concerns. While the increase in green category species indicates improved access to some resources, the decline in yellow and red category species raises alarms about the long-term viability of these resources. The growing scarcity of yellow category species and the near-extinction of red species point to the need for immediate action to ensure the sustainable management of flora resources in the region. It is clear that unsustainable harvesting, land conversion for agriculture, and climate stress are major contributors to the decreasing availability of many species.

To address these issues, there is a need to implement more sustainable agricultural practices, such as agroforestry, which can protect both wild and cultivated species while improving soil health and biodiversity. Strengthening conservation efforts and promoting sustainable land-use policies are essential to halt the decline of these species. Additionally, climate adaptation strategies should be considered to help mitigate the effects of climate change on the flora of Mount Merbabu.

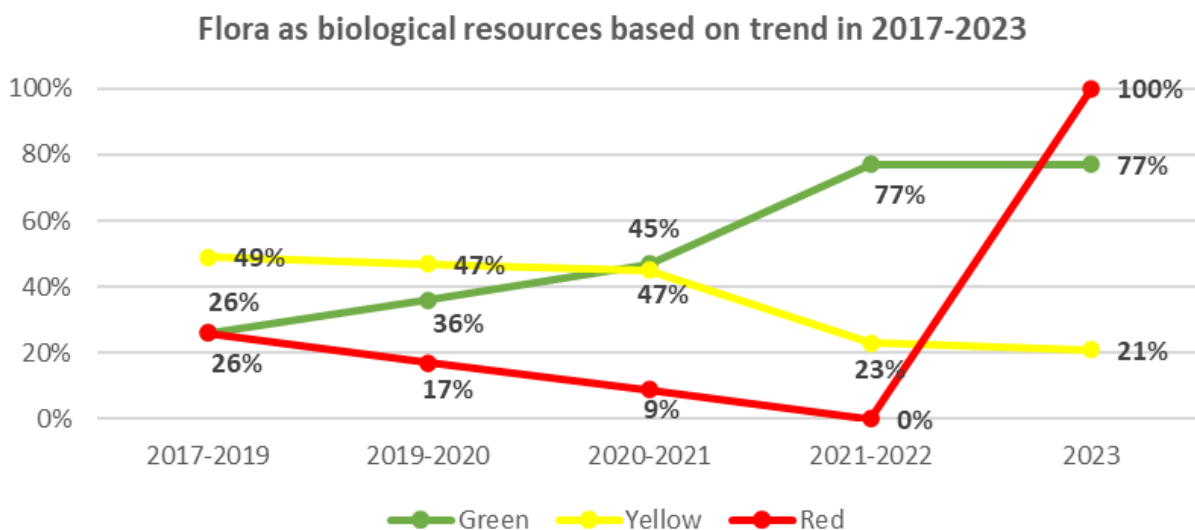


Figure 2. Flora as biological resources based on trend in 2017-2023. Notes: Green = It is readily accessible and obtainable, making it suitable for both personal requirements and as a source of income. Yellow = Still readily available and simple to locate, but limited. Red = Difficult to locate

Table 2. The existence of flora biological resources used as a source of livelihood by the people of Ngagrong, Candisari, and Ngargoloka Villages, Gladagsari Subdistrict, Boyolali Dsitrict.

Biological resources		Time				
Scientific name	Local name	2017-2019	2019-2020	2020-2021	2021-2022	2023
Flower plants						
<i>Aloe vera</i> (L.) Burm.f.	Lidah buaya	Yellow	Yellow	Green	Green	Green
<i>Begonia acetosa</i> Vell.	Begonia bulat	Yellow	Yellow	Green	Green	Green
<i>Begonia</i> sp.	Begonia marmaduke	Yellow	Yellow	Green	Green	Green
<i>Begonia obliqua</i> L.	Sayap malaikat	Yellow	Yellow	Green	Green	Green
<i>Brugmansia</i> sp.	Bunga terompet	Yellow	Yellow	Green	Green	Green
<i>Calliandra houstoniana</i> var. <i>calothyrsus</i> (Meisn.) Barneby	Kaliandra merah	Yellow	Yellow	Green	Green	Green
<i>Cananga odorata</i> (Lam.) Hook.f. & Thomson	Bunga kenanga	Yellow	Yellow	Green	Green	Green
<i>Canna hybrida</i> Hort.	Bunga tasbih	Red	Yellow	Green	Green	Green
<i>Erythrina subumbrans</i> (Hassk.) Merr.	Dadap serep	Yellow	Yellow	Green	Green	Green
<i>Melastoma malabathricum</i> L.	Senggani senduduk	Yellow	Yellow	Green	Green	Green
<i>Mentha piperita</i> L.	Mint	Red	Yellow	Green	Green	Green
<i>Pachystachys lutea</i> (Ruiz & Pav. ex Schult.) Nees	Bunga lilin emas	Yellow	Yellow	Green	Green	Green
<i>Sansevieria trifasciata</i> Prain	Lidah mertua	Yellow	Yellow	Green	Green	Green
<i>Tradescantia pallida</i> (Rose) D.R.Hunt	Hati ungu	Yellow	Yellow	Green	Green	Green
Fruit Plants						
<i>Artocarpus heterophyllus</i> Lam.	Nangka	Red	Yellow	Green	Green	Green
<i>Annona muricata</i> L.	Sirsak	Red	Yellow	Green	Green	Green
<i>Capsicum annuum</i> L.	Cabai merah	Green	Green	Green	Green	Green
<i>Capsicum frutescens</i> L.	Cabai hijau	Green	Green	Green	Green	Green
<i>Carica papaya</i> L.	Pepaya	Yellow	Yellow	Green	Green	Green
<i>Citrus × aurantium</i> L.	Jeruk medan	Red	Yellow	Green	Green	Green
<i>Durio zibethinus</i> Murray	Durian	Yellow	Yellow	Green	Green	Green
<i>Mangifera indica</i> L.	Mangga	Yellow	Yellow	Green	Green	Green
<i>Manihot esculenta</i> Crantz	Singkong	Yellow	Yellow	Green	Green	Green
<i>Musa acuminata</i> balbisiana Colla	Pisang kepok	Green	Green	Green	Green	Green
<i>Musa paradisiaca</i> var. <i>sapientum</i>	Pisang ambon	Green	Green	Green	Yellow	Green
<i>Nephelium lappaceum</i> L.	Rambutan	Red	Yellow	Green	Green	Green
<i>Persea americana</i> Mill.	Alpukat	Yellow	Yellow	Green	Green	Green
<i>Salacca zalacca</i> (Gaertn.) Voss	Salak	Yellow	Yellow	Green	Green	Green
<i>Solanum lycopersicum</i> L.	Tomat	Yellow	Yellow	Green	Green	Green
<i>Zea mays</i> L.	Jagung	Yellow	Yellow	Green	Green	Green
Herbaceous						
<i>Cibotium barometz</i> (L.) J.Sm.	Pakis monyet	Yellow	Yellow	Green	Green	Green
<i>Cymbopogon citratus</i> (DC.) Stapf	Serai	Yellow	Yellow	Green	Green	Green
<i>Nicotiana tabacum</i> L.	Tembakau	Yellow	Yellow	Green	Green	Green
<i>Pennisetum purpureum</i> Schumach.	Rumput gajah	Green	Green	Green	Green	Green

Rhizome

Alpinia galanga (L.) Willd.

Curcuma longa L.

Curcuma zanthorrhiza Roxb.

Kaempferia galanga L.

Zingiber officinale Roscoe

Woody Plants

Acacia mangium Willd.

Albizia chinensis (Osbeck) Merr.

Casuarina sp.

Garuga floribunda Decne.

Guadua angustifolia Kunth

Swietenia mahagoni (L.) Jacq.

Syzygium aromaticum L.

Tectona grandis L.f.

Toona sureni (Blume) Merr.

Lengkuas

Kunyit

Temulawak

Kencur

Jahé

Akasia

Sengon

Cemara

Wiu

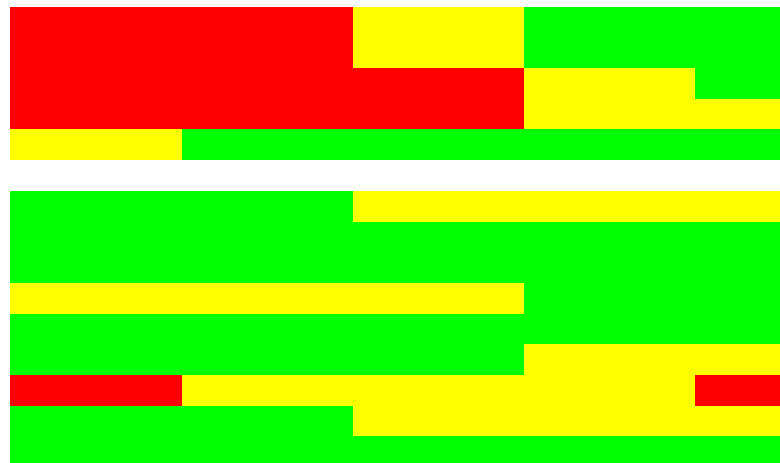
Bambu kolombia berduri




Mahoni

Cengkeh

Jati

Suren

**Note:**

-  = It is readily accessible and obtainable, making it suitable for both personal requirements and as a source of income.
-  = Still readily available and simple to locate, but limited.
-  = Difficult to locate

During 2017-2019 period, *Aloe vera* (L.) Burm.f. (*lidah buaya*), *Begonia* spp., and *Calliandra houstoniana* var. *calothyrsus* (Meisn.) Barneby were some of the key plants cultivated and used by the community. Lanka (2018) stated that *A. vera*, known for its medicinal and cosmetic uses, was widely utilized and remains one of the most consistent species in the region. *Begonia* sp. and *C. houstoniana* var. *calothyrsus* are also important as ornamental plants, contributing to local aesthetics and culture. During this period, the plant species recorded in the region showed a stable presence, with several species being consistently utilized by the local communities. These fruit-bearing species were present but not yet fully integrated into commercial farming in the region. *Cengkeh*/cloves (*Syzygium aromaticum* (L.) Merr. & L.M.Perry) were present but low yield and sporadic in some areas due to market instability. Plants like *A. vera* and *Begonia* spp. maintained their presence due to their importance in local health systems and cultural practices, while fruit trees were more scattered and not yet heavily cultivated.

Period 2019-2020 were growing interest in medicinal and economic crop. From 2019 to 2020, there was a noticeable increase in the cultivation of medicinal plants and a greater focus on fruit crops. *Curcuma longa* L. (*kunyit*/turmeric) and *Zingiber officinale* Roscoe (*jahe*/ginger): These plants, along with other medicinal herbs, saw increased cultivation in response to market demand for natural remedies. *M. indica* (*mangga*/mango) and *C. papaya* (*papaya*/papaya), continued to thrive, now becoming more commercially viable. Cloves showed a decline in some areas due to low economic returns, reflecting market shifts and the choice of farmers to invest more in fruit crops or *Nicotiana tabacum* L. (tobacco).

From 2020-2021 is period for resilience and expansion of medicinal plants. During 2020-2021, the community saw a continued rise in medicinal plant use, possibly linked to increasing interest in natural health products amidst the COVID-19 pandemic (Pieroni et al. 2020). Medicinal plants like *C. longa* and *Z. officinale* became more prevalent as self-reliance in health care increased within the community. Mango and papaya continued to be reliably present, indicating the growing importance of fruit crops for both local consumption and economic gain. The decline in clove trees persisted, driven by market dynamics and economic instability.

In 2021-2022 was period for diversification and adaptation to market pressures, the local farming landscape began to diversify, with farmers opting for crops that aligned better with market demand and climate adaptability. Cloves saw further decline, while crops like vegetables and tobacco became more prominent in farming practices. Medicinal plants continued to increase, and new species were incorporated into community gardens. Fruit crops remained a consistent part of the landscape, with *M. indica* and *C. papaya* leading the way as staple crops.

When 2022-2023 was the period for stabilization and focus on sustainability by 2023, the region saw stabilization in the availability of certain species, with a clearer focus on sustainability in resource management. Mango and papaya remained consistent and crucial for

economic security, while medicinal plants continued to grow in cultivation and cultural significance. Cloves were nearly absent due to low profitability, while other crops like tobacco continued to dominate. Woody species like *Tectona grandis* L.f. (*jati*/teak) were maintained due to their role in soil stabilization and commercial timber use.

The flora resources listed in Table 2 and Figure 3 provide a range of ecological benefits beyond their economic and cultural roles, on the eastern slopes of Mount Merbabu are diverse and provide essential functions to the local ecosystem, economy, and culture. These resources can be categorized into rhizomes, flowering plants, fruit plants, herbaceous plants, and woody plants, each with specific roles in supporting biodiversity, local livelihoods, and cultural practices.

Flowering plants (30%), such as *Brugmansia* spp. and *Erythrina subumbrans* (Hassk.) Merr. play a significant role in maintaining pollinator populations, such as bees and butterflies, which are crucial for ecosystem functioning. These plants, while used for ornamental purposes, also contribute to the reproductive success of many agricultural crops. The integration of flowering species into agroecosystems can thus enhance pollination and support agricultural productivity. Flowering plants are crucial for pollination. They provide nectar and pollen to a variety of pollinators such as bees, butterflies, and birds, which in turn support the reproductive success of many species, including agricultural crops (Sumalatha et al. 2024). They also support a range of wildlife by providing food and shelter. Flowering plants such as *C. odorata* are commercially valuable for essential oils, used in the fragrance industry. Others like *A. vera* are utilized for their medicinal and cosmetic benefits. Cultural uses of flowering plants, particularly in traditional rituals and ceremonies, also add to their economic value, especially in the context of local tourism and cultural events.

Biological resources from flora

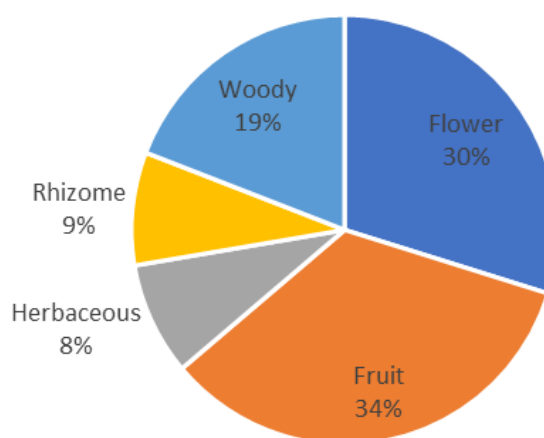


Figure 3. The composition flora as biological resources for local communities

Fruit plants represent the largest category, comprising about (34%) of the species. This is not surprising given the agricultural importance of fruit-bearing species like *M. indica* (mangga/mango), *C. papaya* (papaya/papaya), and *C. sinensis* (jeruk/orange). These plants provide essential food security to the local population, offering a reliable source of nutrient-rich produce. Additionally, fruit crops like mango and papaya are significant cash crops, contributing to economic income through local sales and trade. These plants are vital for both food security and income generation in the local communities. Fruit trees contribute to biodiversity by providing habitat and food sources for a variety of wildlife, including birds, mammals, and insects (Mariyappan et al. 2023). They also help in maintaining soil fertility through their leaf litter, which decomposes and provides nutrients to the soil (Srivastava et al. 2021). Fruit trees are often part of agroforestry systems, which improve land productivity while conserving ecosystem health. Ecologically, fruit plants also play an important role in ecosystem stability. Their fruit provides food for a variety of wildlife, including birds, mammals, and insects. Moreover, these plants often grow in agroforestry systems, which help maintain soil health, reduce erosion, and enhance biodiversity by integrating trees with crops. Fruit crops such as *M. indica*, *C. papaya*, and *C. sinensis* are crucial for the local economy. These plants contribute to both subsistence and commercial farming, providing nutrient-rich food for the local population and creating opportunities for market trade. The rising demand for tropical fruits in domestic and international markets has made these crops an important source of income.

Herbaceous plants, in the context of plant habitus, make up (9%) of the species in the region. These plants have soft, non-woody stems and include species like *C. citratus* (serai/lemongrass), *C. barometz* (pakis monyet/monkey fern), and *N. tabacum*. Herbaceous plants contribute to the understory of both forests and agroecosystems. Their root systems help to maintain soil integrity and prevent erosion, especially in areas with sloped terrain. These plants also help maintain moisture levels in the soil and provide habitats for insects and small animals (Perea et al. 2021). Many herbaceous plants are used in traditional medicine, as seen with lemongrass and tobacco. *N. tabacum*, in particular, is a significant cash crop, while lemongrass is cultivated for its use in culinary and medicinal products. These plants have both local and global economic importance due to their versatility in health products and commercial trade.

Rhizomes (9%), which include species like *C. longa*, *Z. officinale*, and *K. galanga* (kencur/aromatic ginger). These plants are primarily cultivated for medicinal and culinary uses. Rhizomes often grow in the understory of forests, playing a role in soil stabilization and erosion control. Their root systems help maintain soil integrity, particularly in areas with sloped terrain, such as those on the eastern slopes of Mount Merbabu. They also contribute to soil health by improving nutrient cycling and creating microhabitats for small organisms. Rhizomes like ginger and turmeric are vital for the local economy (Thakur 2024).

These plants are sold in local markets and are important for traditional medicine and culinary practices. As demand for herbal remedies and natural food products increases globally, the economic importance of these species also grows. Rhizomes are often cultivated in small-scale farming systems, contributing to economic resilience in rural areas. Medicinal plants, such as *C. longa* and *Z. officinale*, contribute to the biodiversity of the region by supporting a variety of microhabitats. These plants are often grown in agroforestry systems, which provide a means of biodiversity conservation within farming landscapes. The integration of medicinal plants into farming systems also supports sustainable land use by combining economic production with ecological conservation (Astutik et al. 2019).

Woody plants, including *T. grandis*, *S. mahagoni*, and *A. mangium*, make up approximately (19%) of the species on Mount Merbabu. Despite being a smaller proportion compared to the other categories, these plants are of critical ecological and economic importance. Teak and mahogany are valuable for timber production, used in construction and furniture-making, providing economic benefits to the community. Woody species like *T. grandis* and *S. mahagoni* contribute to soil stabilization, reduce erosion, and play a role in carbon sequestration. These species are essential not only for their timber and economic value but also for their role in maintaining ecosystem integrity. Their growth in sloped areas helps to prevent soil degradation and maintain land productivity, which is crucial in areas like Mount Merbabu, where the landscape is prone to erosion due to the volcanic terrain. Woody plants are crucial for forest ecosystems as they provide habitat for a range of wildlife, improve soil fertility, and contribute to carbon sequestration. These trees help in stabilizing the soil, preventing erosion, and maintaining the hydrological balance in the region (Jafari et al. 2022). Their role in biodiversity conservation is also significant, as they provide habitats for species that rely on forested areas. Trees like teak are important for the timber industry, used in construction, furniture making, and craftsmanship. Mahogany is also highly valued for its wood, making these species significant contributors to the local economy.

However, sustainable management practices are essential to prevent overharvesting and ensure that these species continue to provide ecological and economic benefits. As woody plants and forests, teak, mahogany, and other tree species contribute to carbon sequestration. This process involves the absorption of carbon dioxide from the atmosphere, which helps mitigate the effects of climate change by reducing the overall greenhouse gas concentration. These trees play a significant role in climate regulation, which is crucial for maintaining the microclimate of Mount Merbabu and surrounding areas. Agroforestry systems that integrate these trees with crops can further enhance carbon storage while maintaining crop productivity (Fahad et al. 2022).

The community's reliance on medicinal plants is deeply embedded in local cultural practices. Plants like *A. vera* and *Mentha piperita* L. (mint) are not only valued for their medicinal properties but also for their cultural significance

in traditional healing practices. These plants are used in rituals, remedies, and even daily consumption. For example, Aloe vera is commonly used in traditional skincare treatments and healing salves. The growing interest in cultivating medicinal plants in recent years, as seen in the data from 2022, reflects a cultural shift towards self-reliance in health practices and a rejuvenation of traditional knowledge. This growing use of herbal remedies aligns with global trends, where communities are increasingly turning to traditional knowledge to address health issues while also promoting sustainable resource use. Globally, the shift towards the cultivation of medicinal plants and natural products has been driven by the increasing demand for plant-based remedies and organic agriculture. In regions such as Southeast Asia and Central America, there has been a growing recognition of the importance of agroforestry systems that integrate medicinal plants and fruit crops into sustainable farming practices (Kumar et al 2023). This mirrors trends seen in Mount Merbabu, where the cultivation of medicinal plants like ginger and turmeric is increasing, partly due to a global rise in demand for natural health products.

In Central Java, similar studies have shown that agricultural diversity, especially in rural areas, is crucial for both economic resilience and biodiversity conservation. For example, study by Leksikowati et al. (2018) stated that integration of flowering species and fruit crops into agroecosystems has been shown to enhance pollination and improve crop yields. These practices, similar to those around Mount Merbabu, not only support local biodiversity but also help the community adapt to changing economic and environmental conditions. While the biological resources in Mount Merbabu provide important cultural, economic, and ecological services, their sustainable management is crucial for long-term resilience. Market-driven agricultural practices, such as the focus on tobacco and cash crops, risk depleting the diversity of local crops and medicinal plants that form the backbone of the community's livelihoods. The decline of clove trees, for instance, shows how market volatility and economic pressures can alter resource availability, making it essential for the community to develop sustainable farming practices that balance economic needs with resource conservation.

The integration of agroforestry, focusing on native plant species and medicinal crops, could improve both biodiversity and farm productivity while supporting economic development. Moreover, the recognition of climate change impacts on agricultural productivity, as seen with fluctuating tobacco yields, further underscores the need for climate-resilient agricultural practices. The flora resources on the eastern slopes of Mount Merbabu, with their diverse species ranging from medicinal plants to fruit-bearing trees, play an integral role in supporting the local community's livelihoods and cultural identity. However, these resources face challenges related to market dynamics, climate change, and sustainability issues. The trends in plant availability over the years demonstrate the complex interactions between economic pressures, climate variability, and local resource management practices. By embracing sustainable agricultural practices, integrating

traditional ecological knowledge with modern conservation strategies, and enhancing the resilience of the farming system, the community can ensure the long-term availability of these vital biological resources.

Fauna as biological resources on the eastern slopes of Mount Merbabu

The data from Table 3 highlights the availability of faunal biological resources used by the communities of Ngagrang, Candisari, and Ngargoloka Villages, located on the eastern slopes of Mount Merbabu. These resources include various species of birds (Aves), mammals (Mammalia), and fish (Pisces) amount 12 species, which are integral to local livelihoods, food security, and cultural practices.

The availability of faunal resources on the eastern slopes of Mount Merbabu has undergone notable changes between 2017 and 2023, with clear shifts in the accessibility and utilization of species by local communities. The data categorizes the faunal species into green, yellow, and red species categories, each reflecting the species' availability and accessibility (Figure 4).

In the period 2017-2019, all species were classified as green, meaning they were readily available and easily obtainable, serving both personal needs and as a source of income. This period likely reflects the relative abundance of faunal resources, with local communities having easy access to a variety of species for consumption and trade. The cultural importance of species such as chickens (*G. gallus*), ducks (*A. platyrhynchos*), and cattle (*B. taurus*) were significant during this period, providing not only food security but also cultural value in traditional ceremonies and local markets.

However, starting in 2019-2020, a noticeable decline in the availability of green species category occurred, dropping to 86%, reflecting potential environmental pressures and increased market demand. This shift could be attributed to overexploitation of domesticated species, land-use changes for agriculture, and growing competition with other areas for natural resources. For example, overhunting, particularly of wildlife species like the civet (*P. hermaphroditus*) and barking deer (*M. muntjak*), may have contributed to this reduction in species accessibility.

From 2020 to 2021, the green species category dropped further to 64%, while the percentage of species in the yellow species category increased to 36%. Species in the yellow species category are still readily available but are becoming more limited, possibly due to habitat degradation, overgrazing, or the effects of climate change. For example, species like cattle and goats (*C. hircus*) continued to be readily available but faced pressure from market-driven demand and the limitations of available grazing land. These economic pressures could have led local farmers to prioritize larger-scale livestock farming over maintaining biodiversity. Additionally, climate variability, including droughts or flooding on the volcanic slopes, could have further stressed both wild and domesticated species (Filipe et al. 2020).

By 2021-2022, the availability of green species category further declined to 50%, while the yellow species

category remained steady at 43%, reflecting a growing scarcity of reliable resources. At the same time, the red species category, representing species that are difficult to locate, increased slightly to 7%, suggesting that certain species, particularly wild mammals and birds, are becoming increasingly rare. The pressure from commercialization, habitat destruction, and unsustainable hunting likely caused the depletion of wild fauna populations, which are now harder to find and utilize by local communities. For instance, wildlife species like parakeets (*P. alexandri*) and civets have likely experienced

population declines due to overexploitation for pet trade and hunting.

In 2023, the trend continued, with green species category dropping to 43% and yellow species category holding steady at 43%. The Red category, which indicates species that are difficult to locate, rose to 14%, signaling an alarming trend in the loss of easily accessible wildlife resources. The difficult-to-locate species likely include key wildlife resources that have been overhunted or migrated away from human settlements due to changes in land use and climate conditions.

Table 3. The existence of Faunal Biological Resources used as a Source of Livelihood by the People of Ngagrong, Candisari, and Nargoloka Villages, Gladagsari Subdistrict, Boyolali District.

Biological Resources		Time				
Scientific Name	Local Name	2017-2019	2019-2020	2020-2021	2021-2022	2023
Aves						
<i>Anas platyrhynchos</i> Linnaeus 1758	Bebek	Green	Green	Green	Green	Green
<i>Copsychus saularis</i> Linnaeus 1758	Burung Kacer	Green	Green	Green	Green	Green
<i>Gallus gallus</i> subsp. <i>domesticus</i> Linnaeus 1758	Ayam kampung	Green	Green	Green	Green	Green
<i>Gallus gallus</i> subsp. <i>domesticus</i> Linnaeus 1758	Ayam potong	Green	Green	Green	Green	Green
<i>Pycnonotus aurigaster</i> Vieillot 1818	Kutilang	Green	Green	Green	Green	Green
<i>Psittacula alexandri</i> Linnaeus 1758	Betet	Green	Green	Green	Green	Green
Mammals						
<i>Paradoxurus hermaphroditus</i> Pallas 1777	Musang	Green	Green	Green	Green	Green
<i>Bos taurus</i> Linnaeus 1758	Sapi potong	Green	Green	Green	Green	Green
<i>Bos taurus</i> Linnaeus 1758	Sapi perah	Green	Green	Green	Green	Green
<i>Capra hircus</i> Linnaeus 1758	Kambing	Green	Green	Green	Green	Green
<i>Muntiacus muntjak</i> Zimmermann 1780	Kijang	Green	Green	Green	Green	Green
<i>Oryctolagus cuniculus</i> Linnaeus 1758	Kelinci	Green	Green	Green	Green	Green
<i>Ovis aries</i> Linnaeus 1758	Domba	Green	Green	Green	Green	Green
Pisces						
<i>Clarias batrachus</i> Linnaeus 1758	Lele	Green	Green	Green	Green	Green

Note:
■ It is readily accessible and obtainable, making it suitable for both personal requirements and as a source of income.
■ Still readily available and simple to locate, but scarce or limited.
■ Difficult to locate

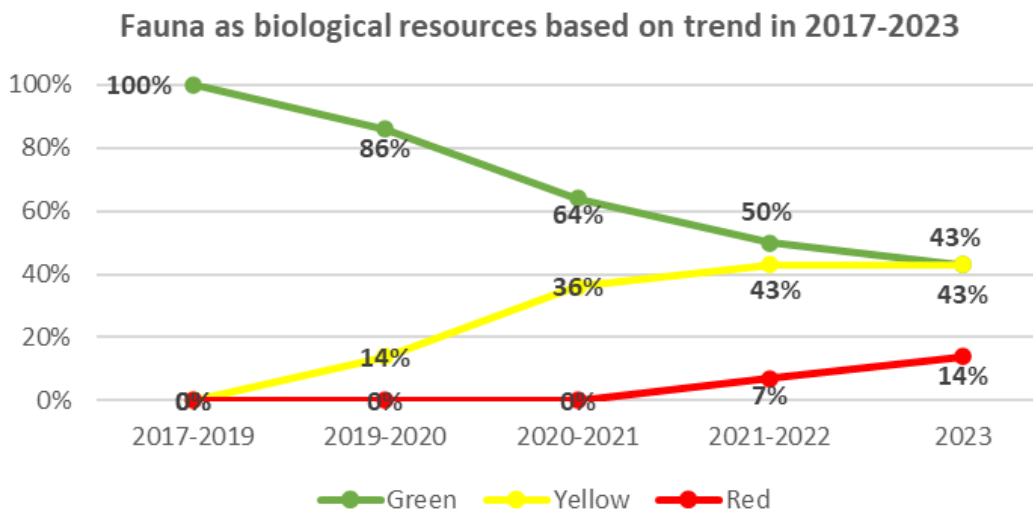


Figure 4. Fauna as biological resources based on trend in 2017-2023. Notes: Green = It is readily accessible and obtainable, making it suitable for both personal requirements and as a source of income. Yellow = Still readily available and simple to locate, but limited. Red = Difficult to locate

Although both local chicken and broiler chickens belong to the same species, *G. gallus* subsp. *domesticus*, they differ significantly in terms of physical characteristics, rearing methods, and economic value. Local chickens are smaller, grow more slowly, and are raised in free-range systems, often used for cultural and ceremonial purposes, with their meat considered more flavorful and nutritious (Yaman 2012). These chickens typically have a higher market price due to their perceived quality and cultural significance, particularly in rural areas like Ngagrang, Candisari, and Ngargoloka. In contrast, broiler chickens are bred for rapid growth and meat production, raised in intensive farming systems with a focus on efficiency, and are more affordable and widely available in urban markets (Tallentire et al. 2016). While broiler chickens are the primary source of chicken meat for everyday consumption due to their lower cost, village chickens remain important for cultural practices and higher-value local markets. Thus, both types of chickens play distinct roles in local economies, with local chickens tied to tradition and broilers meeting the demands of mass production and affordability.

Similar to the case with *G. gallus* subsp. *domesticus* (chicken), where local and broiler chickens are the same species but perceived and utilized differently, *B. taurus* (cattle) also exhibits distinct roles when raised as dairy cattle (*sapi perah*) versus beef cattle (*sapi potong*). Despite both being the same species, the dairy cattle are valued for their higher milk yield and docile temperament, making them ideal for milk production and providing ongoing income through milk sales. They are also culturally significant, often used in ceremonies and festivals. In contrast, beef cattle are raised primarily for meat production, selected for their larger size and faster growth, and are mainly sold for beef, particularly during festivals, where they hold cultural importance as symbols of wealth (Hozáková et al. 2020). The market price of dairy cattle is generally higher due to continuous milk production, while beef cattle generate higher returns when sold for meat. Though both types of *B. taurus* play vital roles in local agriculture and culture, the perception and utilization by the community differ significantly based on their economic contribution and cultural relevance.

This suggests that these species are well-integrated into local farming systems, providing both sustenance and a source of income. The availability of *B. taurus* (*sapi/cattle*), *C. hircus* (*kambing/goats*), and *O. cuniculus* (*kelinci/rabbits*) was also stable, reflecting the importance of livestock in the local economy. These domesticated species serve as reliable sources of food and cultural value, with cattle, for example, playing a prominent role in traditional ceremonies and as a status symbol (Liufu et al. 2023). The availability of *C. batrachus* (*lele/catfish*) was steady throughout this period, indicating a well-established practice of aquaculture, which provided a reliable food source. This reflects the growing importance of fish farming in supporting the local economy and providing a consistent resource for the community. However, the presence of wild species like *P. hermaphroditus* (*musang/civet*) and *M. muntjak* (*kijang/barking deer*) remained somewhat variable, suggesting potential

ecological pressures or hunting practices that could be impacting their populations.

Aves make up 43% (Figure 5) of the faunal biological resources, which is a significant portion. This reflects the importance of birds, both domesticated and wild, in the livelihoods of the local population. Species like *G. domesticus* subsp. *domesticus* and *C. saularis* (*kacer*) are not only crucial for food production but are also tied to cultural practices, such as bird-keeping competitions. The presence of both local and pet species suggests a deep connection between the community and avian species, with birds playing a key role in both economic and social aspects of rural life (Dai et al. 2021).

Mammals dominate the faunal composition, comprising 50% of the total biological resources (Figure 5). This highlights the reliance on domesticated mammals such as *B. taurus*, *C. hircus*, and *O. cuniculus* for food, income, and cultural purposes. The stable presence of these species underscores their critical role in the agricultural system of the villages, where livestock farming is essential for daily sustenance, ceremonial events, and as a symbol of wealth. The higher percentage of mammals also reflects their direct and substantial contribution to the community's economy and way of life.

Pisces, represented by *C. batrachus*, make up a smaller portion of the faunal resources at 7% (Figure 5). While fish farming, particularly catfish, plays an important role in local aquaculture and provides a steady source of food, it is less dominant compared to mammals and birds. The relatively lower percentage could reflect the lesser reliance on fish compared to other domesticated animals, or it might suggest that fish farming is more localized or secondary to other forms of agriculture in the region. The higher percentage of mammals and birds indicates a system that is largely shaped by human-managed environments, where domesticated species thrive. These species are well-suited to the agricultural practices and land-use patterns on the slopes of Mount Merbabu. However, the relatively low proportion of fish suggests that the local aquatic ecosystems may not be as heavily utilized or that aquaculture is still developing in comparison to terrestrial farming.

Biological resources from fauna

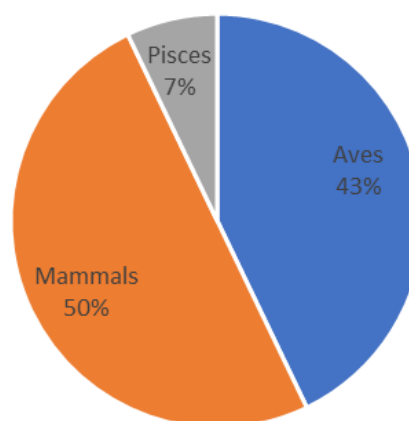


Figure 5. The composition of fauna as biological resources for local communities

The dominance of mammals and birds is closely linked to cultural practices in the region. Livestock such as cattle and goats are essential not only for food and income but also for traditional ceremonies and community events. Birds, particularly those used in competitions or as pets, are integral to local traditions. The smaller percentage of fish may reflect a cultural preference for terrestrial animals or a historical focus on livestock farming. While domesticated mammals and birds make up the majority of the fauna, their dominance may also indicate a shift from wild to domesticated species over time. This shift could be a result of human population growth, land-use changes, and the increasing domestication of animals for economic and social reasons (Begna 2021; Ellis 2021). The lower proportion of fish might also suggest that local ecosystems, though utilized for aquaculture, still have more room for development or sustainability in the future.

Biological resources, livelihood functions, and sustainability concerns

The biological resources of the eastern slopes of Mount Merbabu are essential to local livelihoods, supporting both subsistence and economic activities. These resources, comprising flora and fauna, serve as vital sources of food, income, and cultural identity. However, the sustainability of these resources faces increasing pressures from monoculture farming, market dependency, and environmental changes (Table 4).

The biological resources on the eastern slopes of Mount Merbabu are essential to the livelihoods of local communities, with agriculture, livestock, and timber serving as the backbone of the economy. Key flora species, including *M. indica* (mango), *D. zibethinus* (durian), *A. heterophyllus* (nangka/jackfruit), and *Z. mays* (corn), provide crucial food security and cash income. These crops, along with staple crops such as cassava and chili, help sustain household food security while generating income through market sales. However, the region's reliance on monoculture farming, particularly of corn and cassava, introduces significant sustainability challenges. Such monoculture systems are inherently vulnerable to fluctuations in market prices, pest outbreaks, and soil degradation, undermining long-term agricultural

productivity. For instance, the vulnerability of cassava to pest infestations and fluctuating market prices has already caused significant economic instability for local farmers.

In contrast to monoculture farming, agroforestry systems, which combine multiple plant species, offer greater ecological and economic resilience. Studies from regions such as Bali and Lombok highlight the advantages of agroforestry, including diversified income sources and enhanced biodiversity. Agroforestry systems improve soil fertility, reduce erosion, and provide habitat for a greater diversity of flora and fauna. The integration of various plant species in agroforestry not only mitigates environmental risks but also provides more stable income for farmers. By contrast, the overreliance on monoculture systems in Merbabu limits ecological resilience, leaving the area more susceptible to environmental shocks such as extreme weather events, soil erosion, and drought challenges that are likely to increase with climate change. Research by Ali et al. (2025b) emphasizes how monoculture systems can lead to diminished soil health and reduced biodiversity, which increase vulnerability to both economic volatility and climate-induced environmental stress.

Timber resources, particularly *T. grandis* and *S. mahagoni* are key to the local economy, providing income through timber sales and contributing to carbon sequestration. However, the dominance of monoculture timber plantations raises significant ecological concerns. Monocultures, particularly those of teak, are highly susceptible to soil degradation, nutrient depletion, and erosion due to the lack of species diversity. These plantations often fail to support vital ecosystem services, such as water retention, soil stabilization, and wildlife habitat provision. Globally, monoculture timber plantations have been linked to the degradation of ecosystem services, making their long-term sustainability questionable (Otazua and Paquette 2018). The shift towards diversified tree planting in agroforestry systems, integrating native species alongside commercial timber trees, could not only mitigate the ecological risks of monoculture timber plantations but also enhance the resilience of these systems to climate change (Moreno et al. 2018).

Table 4. Linkages between categories of biological resources, livelihood functions, and sustainability concerns

Resource category	Main livelihood functions	Ecological roles	Main sustainability concerns
Fruit plants	Cash income, household food	Shade, soil protection, habitat for fauna	Market dependence, conversion to monoculture, climate risk
Rhizome	Traditional medicine, small-scale trade	Soil stabilization, microhabitats	Overharvesting if demand spikes, dependence on small plots
Woody plants	Timber income, construction material	Carbon storage, erosion control	Monoculture plantations, biodiversity loss
Mammals	Meat, milk, ceremonial value	Nutrient cycling, grazing impact	Overgrazing, disease, land competition
Birds	Food, trade, ornamental/singing, cultural competitions	Seed dispersal, insect control	Overharvesting (songbirds), trade pressure
Fish	Protein source, supplemental income	Aquatic nutrient cycles	Water quality, disease, small-scale viability

Livestock farming remains central to the livelihoods of local communities in Merbabu, with cattle (*Bos taurus*), goats (*C. hircus*), and sheep (*O. aries*) providing essential sources of food, income, and cultural value. These animals are integral to local traditions and social cohesion, particularly in the form of *selamatan* (community feasts). However, intensification of livestock farming, particularly cattle grazing, is leading to overgrazing, soil erosion, and vegetation loss, which reduces the land's productivity and biodiversity. The cultural significance of livestock, especially as symbols of wealth and status, further compounds the pressures on available resources (Price and Makarewicz 2024). Overgrazing leads to the degradation of pasturelands, limiting the area's capacity to support sustainable agricultural practices and contribute to food security.

The decline of wildlife in the region, such as the civet (*P. hermaphroditus*) and barking deer (*M. muntjak*), reflects broader ecological pressures, including overgrazing, overhunting, and habitat destruction. Overexploitation and habitat fragmentation are major drivers of species decline globally (Hald-Mortensen 2023). In Merbabu, the reduced availability of these species highlights the need for integrated conservation strategies that balance cultural traditions with ecological preservation. Sustainable grazing practices, such as rotational grazing, the establishment of protected grazing areas, and reforestation efforts, are essential for mitigating the negative impacts of livestock farming on biodiversity.

Climate change poses significant threats to the biological resources of Merbabu, exacerbating existing sustainability challenges. As environmental conditions shift, agricultural systems reliant on monoculture crops become increasingly vulnerable to pests, drought, and economic instability. The growing pressure on natural resources is compounded by market dependency, which leaves local communities highly vulnerable to economic shocks when crop yields or livestock productivity decline due to climate-related stresses (Erdoğan et al. 2021). For instance, the decline in tobacco yields in the region has been partly attributed to changing rainfall patterns and temperatures. The increased frequency of extreme weather events, such as floods and droughts, further undermines the resilience of monoculture systems.

To address these climate-induced challenges, the integration of agroforestry systems is a promising solution. Agroforestry systems, which combine diverse crops and tree species, are better suited to withstand environmental stressors such as fluctuating temperatures and rainfall patterns. These systems promote soil health, improve water retention, and enhance biodiversity, all of which contribute to the long-term resilience of agricultural systems. Furthermore, agroforestry systems can provide farmers with diversified income sources, reducing their vulnerability to market fluctuations and climate change.

Balancing economic development with the conservation of biological resources is a critical concern, particularly in regions like Merbabu where increasing demand for land, resources, and economic growth can lead to unsustainable practices. To achieve sustainable development, it is

essential to explore alternative livelihoods that do not compromise the environment. Renewable energy, eco-tourism, and sustainable aquaculture represent viable alternatives that can help reduce the pressure on natural resources while generating income for local communities. For instance, eco-tourism can provide economic opportunities by capitalizing on the region's rich biodiversity, while also promoting conservation efforts.

Moreover, policies that encourage the responsible use of biological resources, such as reforestation programs, sustainable agricultural practices, and responsible fishing, are critical in ensuring the long-term sustainability of ecosystems. The government should incentivize sustainable farming practices, such as agroforestry, and support community-based resource management efforts. This can be achieved through financial incentives, technical assistance, and capacity-building programs that empower local communities to take an active role in conservation and sustainable agriculture.

To optimize the utilization of biological natural resources in Indonesia, several key policies and strategies are essential. First, promoting agroforestry systems that integrate diverse crops, fruit trees, and timber species can enhance biodiversity, improve soil health, and increase resilience to climate change. Policies should incentivize sustainable farming practices, reduce dependency on monoculture systems, and foster ecological balance. Strengthening the enforcement of conservation laws is also crucial to combat overexploitation, particularly of wildlife and timber species.

Additionally, the government should invest in education and capacity-building programs focused on sustainability, offering training on climate adaptation, sustainable farming practices, and biodiversity conservation. Promoting alternative livelihoods such as eco-tourism, non-timber forest products, and sustainable aquaculture can further reduce pressure on natural resources. Lastly, a circular economy approach should be incentivized, where agricultural waste is repurposed for bioenergy production or other sustainable uses, reducing environmental impacts while generating new economic opportunities. By adopting these strategies, Merbabu can serve as a model for other regions facing similar pressures, ensuring the sustainable management of biological resources and balancing economic, cultural, and ecological goals for long-term resilience.

In conclusion this study on the utilization of biological resources on the eastern slopes of Mount Merbabu identified 47 species of flora, with fruit plants making up the largest portion at 34%, and 12 species of fauna, where mammals dominated at 50%. Key flora resources, such as mango, papaya, and turmeric, contribute significantly to food security and income, while medicinal plants have seen increased cultivation in response to growing demand for natural health products. Domesticated fauna, including cattle, goats, and chickens, remain central to local livelihoods and cultural practices. However, wild species like civet and barking deer have experienced fluctuating availability, signaling ecological pressures. These trends highlight the community's reliance on domesticated species

and market-driven crops, but also the challenges posed by market fluctuations, habitat loss, and over-exploitation. Sustainable resource management is crucial to balance economic development, cultural traditions, and environmental conservation for the long-term viability of the region's biological resources. The utilization of biological resources on the eastern slopes of Mount Merbabu reveals significant trends in both flora and fauna from 2017 to 2023. Flora resources such as fruit crops, medicinal plants, and woody species constitute a large part of local resource use. Over the years, the cultivation of medicinal plants like *Curcuma longa* (turmeric) and *Zingiber officinale* (ginger) increased, driven by market demand for natural health products, especially during the COVID-19 pandemic. The increasing cultivation of medicinal plants such as *C. longa* (turmeric) and *Z. officinale* (ginger), driven by market demand, offers a model for how the community can diversify and adapt resource use in a sustainable way. However, this shift must be carefully managed to avoid over-exploitation, ensuring both economic growth and biodiversity conservation. By implementing these strategies, Merbabu can serve as a model for other regions facing similar challenges, ensuring that its biological resources continue to provide for local communities while preserving ecological integrity.

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