PRODUCTIVITY AND ECONOMIC IMPACT OF BAMBOO IN MONOCULTURE VERSUS MIXED SYSTEMS: IMPLICATIONS FOR SOCIAL FORESTRY

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PRODUCTIVITY AND ECONOMIC IMPACT OF BAMBOO IN MONOCULTURE VERSUS MIXED SYSTEMS: IMPLICATIONS FOR SOCIAL FORESTRY. Bamboo forest holds significant potential for enhancing social forestry and community welfare. This study aims to compare bamboo's productivity and economic contribution in monoculture versus mixed systems in one of the village forests in Indonesia and analyze the implications for social forestry management. Using a quantitative approach with systematic sampling on 21 plots (14 monoculture plots, six mixed plots, and one pure shrub plot), data on bamboo 'clumps' (a group of bamboo plants that grow closely together) and 'culms' (the individual stems of the bamboo plant) dimensions and regeneration proportion were collected. Statistical analysis employed the Mann-Whitney U non-parametric test to compare two independent groups when the dependent variable is not normally distributed. Results showed that monoculture bamboo had higher productivity and economic contribution, averaging 6,374 culms per hectare per year and an estimated monetary value of IDR 50,992,000 per hectare per year, compared to 5,242 culms per hectare per year in mixed systems. Moreover, the monoculture system had a higher proportion of young bamboo (30.8%) than the mixed system (27.0%). Yet, the result shows the need to fairly balance economic benefits for the local community by strengthening the Management Institution of Village Forest (LPHD) in managing the bamboo supply chain. Implementing an agroforestry system that integrates bamboo with perennial plants and other non-timber forest products may also offer an effective solution for the local community, who cultivates bamboo plants on their own land. The implications emphasize government support in enhancing community capacity, providing market access, and regulations to promote sustainable practices in social forestry. Balancing productivity and sustainability in bamboo forest management can improve local welfare while maintaining forest ecosystems, aligning with Indonesia's social forestry objectives.

Keywords: bamboo, economic contribution, monoculture, agroforestry, production, village forest

PRODUKTIVITAS DAN DAMPAK EKONOMI BAMBU DALAM SISTEM MONOKULTUR DIBANDINGKAN CAMPURAN: IMPLIKASI UNTUK PERHUTANAN SOSIAL. Pengelolaan hutan bambu berpotensi mendukung program perhutanan sosial dan meningkatkan kesejahteraan masyarakat. Tujuan penelitian ini membandingkan produktivitas dan kontribusi ekonomi bambu pada sistem monokultur dan campuran di hutan desa, serta menganalisis implikasinya pada perhutanan sosial. Dengan pendekatan kuantitatif, diambil sampel sistematik pada 21 plot (14 plot monokultur, enam plot campuran, dan satu plot semak belukar), mencakup data rumpun, batang, dan proporsi regenerasi bambu, dan dianalisis dengan uji Mann-Whitney U. Hasil menunjukkan bahwa bambu monokultur lebih produktif dan memberikan kontribusi ekonomi lebih tinggi, dengan rata-rata 6,374 batang per hektar per tahun dan nilai ekonomi sekitar Rp 50,992,000 per hektar per tahun, dibandingkan dengan 5,242 batang per hektar per tahun dalam sistem campuran. Lebih jauh, sistem monokultur memiliki proporsi bambu muda lebih tinggi (30.8%) dibandingkan sistem campuran (27.0%). Namun demikian, hasil menunjukkan pentingnya menyeimbangkan manfaat ekonomi yang berkeadilan untuk masyarakat lokal dengan menguatkan peranan Lembaga Pengelola Hutan Desa (LPHD) dalam mengelola rantai pasok bambu. Implementasi agroforestri yang menggabungkan bambu dengan tanaman tahunan dan hasil hutan bukan kayu lainnya dapat menjadi solusi efektif untuk masyarakat lokal yang membudidayakan bambu

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di lahan miliknya sendiri. Implikasi penelitian ini menekankan perlunya dukungan pemerintah dalam meningkatkan kapasitas masyarakat, menyediakan akses pasar, dan menyesuaikan regulasi yang mendukung praktik pengelolaan bambu berkelanjutan. Keseimbangan antara produktivitas dan keberlanjutan dapat meningkatkan kesejahteraan masyarakat dan kelestarian hutan, sesuai dengan tujuan perhutanan sosial.

Kata kunci: bambu, kontribusi ekonomi, budidaya tunggal, agroforestri, produksi, hutan desa

I. INTRODUCTION

Sustainable forest resource management is a crucial global issue , especially when facing the challenges of deforestation, land degradation, and climate change. Uncontrolled forest exploitation has caused significant ecosystem damage, threatened biodiversity, and reduced the forest's capacity to provide ecosystem services, such as carbon sequestration and hydrological cycle regulation (Morán-Ordóñez et al., 2020). In addition to ecological impacts, forest destruction has socio-economic impacts, especially for local communities that depend on forest resources for their livelihoods (López-Carr, 2021).

In this context, social forestry has emerged as an alternative approach that integrates environmental conservation with improved local community welfare. Social forestry grants forest management rights to communities, assuming that active community participation can increase the effectiveness of conservation and provide direct economic benefits (Condro et al., 2022; Gunawan & Afriyanti, 2019; Kiss et al., 2022). In Indonesia, social forestry is implemented through various schemes, such as Village Forests (VF), Community Forestry (CF), Community Plantation Forests (CPF), Forestry Partnership (FP), and Customary Forest (CuF), to reduce poverty, create sustainable employment, and maintain forest sustainability (Ministry of Environment Forestry of the Republic of Indonesia, 2021; Fisher et al., 2019; Rodd et al., 2022; Octavia et al., 2022a; 2022b).

The social forestry approach is based on the theory of community participation in natural resource management. This theory emphasizes the importance of the local communities' involvement in decision-making and forest management to achieve ecological and socio-economic sustainability (Ballullaya et al., 2019; Kusumadewi et al., 2024; Laudari et al., 2024). Community participation is considered to increase a sense of ownership and responsibility for the sustainability of forest resources, which can reduce environmental destruction practices such as illegal logging (Kaskoyo et al., 2019). The concept of agroforestry serves as an essential theoretical framework for this study. Agroforestry is a land use system that combines forestry and agricultural practices to create a more productive, sustainable, and diverse system (Suparyana & Utama, 2023; Wong et al., 2020).

In the context of bamboo, agroforestry can increase land productivity by combining bamboo with other plants, and increase biodiversity and ecosystem function (Akoto et al., 2020). Similarly, understanding forest areas' carrying capacity and landscape potential, highlighted in studies on mountain-based destinations and national parks, provides critical insights for integrating conservation goals with sustainable management and forestry practices (Rahmafitria & Nurazizah, 2022). These balancing concepts are relevant in bamboo agroforestry.

The effective social forestry practices depend on the management systems, particularly in cultivating economically valuable species like bamboo. Bamboo cultivation has gained attention due to its rapid growth, versatility, and potential for ecological restoration and economic development (Ekanayake et al., 2021; Wong et al., 2020). Bamboo can contribute to soil stabilization, carbon sequestration, and biodiversity enhancement while providing material for construction, handicrafts, and other products (Akoto et al., 2020). In this regard, managing behavior and resource access can influence conservation outcomes and socio-economic benefits (Rahmafitria et al., 2024). For instance, insights from Komodo National Park, where conservation practices have been integrated with local community participation, highlight how sustainable management strategies can enhance ecological preservation and economic benefits. Such examples can guide the sustainable management of bamboo forests under social forestry schemes. However, the method of bamboo cultivation—whether through monoculture or mixed systems—can significantly influence these outcomes.

Previous studies have predominantly focused on the ecological aspects or general productivity of bamboo plantations without directly comparing monoculture and mixed systems within the context of social forestry (Minang et al., 2019; Yahya et al., 2022). This presents a research gap in understanding how different cultivation systems impact productivity and economic contribution, and their implications for sustainable forest management. Additionally, community readiness underscores the potential for integrating conservation-based forest management with tourist-driven economic opportunities (Rahmafitria et al., 2016).

Comparing monoculture and mixed bamboo cultivation systems is essential because each system offers distinct advantages and challenges that affect ecological sustainability and economic viability. Monoculture systems can maximize short-term financial returns with higher yields and simpler management. However, these systems often decrease soil fertility, increase pest vulnerability, and reduce biodiversity over time (Belete & Yadete, 2023; Rączkowska, 2019). In contrast, mixed systems integrate bamboo with other plant species, potentially enhancing ecosystem health, improving soil quality, and providing diversified income sources (Isukuru et al., 2023; Sulistyono et al., 2018). Even though agroforestry needs a more comprehensive approach and may gain slower economic returns, it offers long-term benefits, particularly in contexts where community livelihoods rely on forest resources. Understanding the trade-offs between these systems is critical for developing sustainable management practices that balance economic needs with ecological integrity, particularly in social forestry schemes.

Kutamanah Village Forest, located in Purwakarta Regency, Indonesia, is an example of the implementation of social forestry in Indonesia (Fiqri, 2023; Putra, 2021). Before being converted into a village forest, this area was a production forest managed by Perum Perhutani (an Indonesian state-owned enterprise responsible for forest management), with a dominance of Broadleaf Mahogany (S*wietenia macrophylla*) and Albizia (*Falcataria moluccana*). The transformation into a village forest gave management rights to the Management Institution of Village Forest (LPHD) of Kutamanah, which consists of local communities.

The community of Kutamanah Village Forest has long depended on apus bamboo, locally known as *bambu tali* (*Gigantochloa apus*), as a primary resource. While this species is used for various purposes in other regions, it is mainly harvested and sold only for building materials. Out of the 1,242 hectares of the village forest, *bambu tali* is intensively planted of 425.03 hectares. Bamboo cultivation in the village is predominantly done through a monoculture system rather than mixed planting. Economic considerations and easy management drive the community's preference for monoculture, as bamboo can be harvested quickly. However, this approach raises ecological concerns, including declined soil fertility, increased vulnerability to pests, and reduced biodiversity (Belete & Yadete, 2023; Rączkowska, 2019).

Historically, the area was not dominated by bamboo but by hardwood forests managed by Perum Perhutani, which restricted the community's access to the land. In response, the community began secretly planting bamboo among the hardwood trees. This mixed system that allowed bamboo to coexist with other plants is resulting in improved ecosystem health and diversification of income sources (Isukuru et al., 2023; Sulistyono et al., 2018). However, driven by economic incentives, bamboo planting became more intensive over time, ultimately leading to the dominance of bamboo in the area's land cover.

Although bamboo has significant economic and ecological potential, no in-depth study has compared the productivity and economic contribution between monoculture and mixed bamboo systems in the Kutamanah Village Forest. Previous studies have focused more on plants' ecological aspects or productivity in general, without directly comparing the two management systems in the context of social forestry. Therefore, this study aims to evaluate the potential and productivity of bamboo in monoculture and mixed systems within Kutamanah Village Forest. It also seeks to analyze the economic contribution of each system to the local community and identify the ecological impacts associated with each cultivation method. The research tries to fill the knowledge gap by comparing these systems and providing actionable recommendations for forest managers and policymakers. The main goal is to develop management recommendations to optimize the balance between economic productivity and ecosystem sustainability.

The urgency of this study is a comprehensive approach to the direct comparison between monoculture and mixed bamboo systems in social forestry. This study assesses the physical productivity of bamboo and considers economic contribution and ecosystem sustainability. This study also recommends forest management practices for improving the local communities' welfare and sustainability.

This study proposes an actionable move to develop social forestry policies in Indonesia. Policymakers may design effective and sustainable strategies by understanding the advantages and drawbacks of bamboo management systems. In addition, this study can also be a reference for other areas with similar conditions, both in Indonesia and other countries that implement social forestry.

II. THEORY

A. Social Forestry

Social forestry is a forest management approach that sets local communities as the main actors in the management and as the main beneficiaries of forest resources sustainably. This concept emerged as a response to the centralized forest management model that often ignores the rights and roles of local communities, which can lead to conflict and forest degradation (Maisaroh, 2022). Through social forestry, it is hoped that there will be an increase in community welfare as well as more effective forest conservation.

In Indonesia, social forestry has become one of the national strategies in forest management. Through the Ministry of Environment and Forestry, the government is targeting to allocate 12.7 million hectares of forest for the social forestry program (OID, 2016). There are five social forestry schemes, included Community Forestry (CF), Village Forest (VF), Community Plantation Forest (CPF), Customary Forest (CuF), and Forestry Partnership (FP). Kutamanah Village Forest is one example of a village forest implemented in Indonesia.

The implementation of social forestry in Indonesia faces various challenges, including tenure certainty, community capacity, and market access. Unclear land access and ownership rights often must be clarified for communities (Angessa et al., 2021; Nugroho et al., 2023). In addition, limited knowledge and skills in sustainable forest management are also challenges for local communities (Savari et al., 2020). Furthermore, restricted market access for communities makes it difficult to market forest products and obtain fair prices (Rochaedi et al., 2021). However, social forestry also offers opportunities for community participation in forest conservation, diversifies income sources, and strengthens local institutions (Fisher et al., 2019).

B. Bamboo Management

Bamboo is an economically and ecologically crucial non-timber forest resource. Globally, bamboo is used in the construction, handicraft, food, and energy industries (Ayer et al., 2023). In Indonesia, bamboo plays a significant role in the lives of rural communities as building materials, household appliances, parts of traditional customs, and sources of income (Yani & Anggraini, 2018).

Bamboo management can be carried out through two systems, namely monoculture systems and mixed systems (agroforestry). The bamboo monoculture system is carried out intensively without mixing with other plants. This system tends to increase bamboo productivity in the short term but can reduce biodiversity and soil fertility (Belete & Yadete, 2023; Rączkowska, 2019). Meanwhile, the mixed system is carried out by integrating bamboo planting with other plants, such as perennial trees or food crops. This system can increase biodiversity, soil fertility, and ecosystem sustainability (Isukuru et al., 2023; Sulistyono et al., 2018). Studies show that monoculture systems produce higher bamboo productivity per unit area than mixed systems (Akoto et al., 2020). However, based on the literature, mixed systems are more ecologically sustainable and can increase long-term income through product diversification (Bonilla, 2021).

In social forestry, bamboo management has the potential to improve community welfare. Fine management may optimize bamboo productivity and maintain environmental sustainability. Community participation in bamboo management can strengthen local institutions and forest management capacity (Maisaroh, 2022).

C. Economic Contribution of Bamboo

The bamboo industry has significant economic value globally (Lugt & King, 2019). In Indonesia, bamboo contributes to the local economy through the craft, construction, and tourism industries (Yani & Anggraini, 2018). Bamboo is also an essential source of income for rural communities, including in the Kutamanah Village Forest. However, optimizing the economic contribution of bamboo faces several challenges, such as limited technology and skills, market access and infrastructure, and policy support (Siddik, 2023). Limitations in processing technology and community skills hinder the development of added value for bamboo products, and these barriers even cause the Kutamanah community to be reluctant to switch to other forms of bamboo utilization. Several government agencies and non-governmental organizations have provided some training and assistance in increasing the added value of bamboo. However, the community still needs help accessing a broader market when the product is finished. This is what makes the community reluctant to change. The existing infrastructure, such as bamboo lamination machines, must be improved, as they are considered difficult to use.

Several steps are needed to increase bamboo's economic contribution and community capacity. Training and technical assistance in bamboo cultivation and processing must be continuously carried out to make the community aware and empowered (Akoto et al., 2020; Prilosadoso, 2018). The government and other stakeholders are responsible for developing market access for the local communities to market and promote their bamboo products (Buchari et al., 2023). The government may support the bamboo industry by making policies and regulations regarding incentives and business mentoring (Boissière et al., 2020).

D. Productivity of Bamboo

Bamboo, a versatile and fast-growing plant, has garnered attention for its potential to enhance land productivity, particularly in agroforestry. In Indonesia's social forestry, bamboo is recognized for improving the local communities' livelihoods and promoting environmental sustainability. As of 2005, Indonesia's bamboo forest spanned approximately 2.1 million hectares, with 0.69 million hectares within state forests and 1.41

million hectares on private or community lands (EBF, 2023; ITTO, 2025). The Indonesian government acknowledges bamboo's potential and prioritizes its social forest program development by initiating community forest and forest restoration. Bamboo can be cultivated in diverse ecosystems, including degraded lands, often unsuitable for traditional crops (Ihsan et al., 2023). Integrating bamboo into social forestry enhances local biodiversity and provides a sustainable income for rural communities (Hani et al., 2024).

Bamboo's ability to thrive in marginal lands allows for rehabilitating degraded areas, contributing to overall land productivity (Nigatu et al., 2020). The appearance of bamboo also results in significant soil quality improvement and carbon sequestration. It indicates an effective way to prevent climate change (Hani et al., 2024). This is particularly relevant in Indonesia, where the government promotes bamboo as a key component of reforestation and sustainable land management strategies.

The productivity of bamboo can be significantly influenced by the cultivation system employed. Studies have demonstrated that bamboo grown in agroforestry systems often exhibits higher productivity than monoculture systems. In some studies about the Land Equivalent Ratio (LER), a metric for assessing productivity difference, indicates that a LER value greater than 1.0 means that agroforestry systems are more productive per unit area than monocultures (Lehmann et al., 2020; Seserman et al., 2019).

Agroforestry systems benefit from the complementary relationships between bamboo and other crops. That kind of relation improves resource efficiency, for example, bamboo's deep roots can enhance soil structure, nutrient availability, and adjacent crops (Xu et al., 2023). Integration of bamboo and other crops benefits the ecological aspect (providing shade, reducing water competition, and enhancing land productivity) (Akoto et al., 2020), as well as the social aspect (diversifying locals' income and enhancing local wisdom). These advantages align with social forestry goals to promote sustainable land use and rural livelihoods. Conversely, monoculture bamboo plantations may be high-yielding but can lead to soil degradation and biodiversity reduction over a long period (Akoto et al., 2020).

E. Theoretical Framework and Relevance of the Study

Community Participation Theory in natural resource management is the basic theory in bamboo management in social forestry. This theory emphasizes that active community participation in natural resource management can increase the effectiveness of resource conservation and community welfare (Gunawan & Afriyanti, 2019; Kiss et al., 2022). Community involvement in bamboo management in social forestry can increase a sense of ownership and responsibility (Kaskoyo et al., 2019).

The concept of sustainable livelihoods is essential in this study due to its concern for integrating the economic, social, and environmental aspects. In bamboo management, it is necessary to balance the community's financial needs and the ecosystem's sustainability. Thus, the implications of this study emphasize the application of agroforestry principles. Agroforestry integrates trees with crops or livestock to improve land productivity and sustainability (Penkauskas et al., 2022; Octavia et al., 2022b). Bamboo agroforestry can increase biodiversity and provide additional economic benefits (Akoto et al., 2020; Kumar et al., 2014).

Although many studies have been conducted on bamboo management and social forestry, there is still a gap in understanding the direct comparison between bamboo productivity and economic contribution in monoculture and mixed systems, especially in Indonesia's social forestry context. This research is relevant because it can fill this gap, support policy, and improve optimal bamboo management practices.

This research tries to fill the knowledge gap by providing empirical data on comparing bamboo productivity and economic contribution in both management systems. Policy support from this research is also carried out by providing a scientific basis for formulating more effective social forestry policies. Through this research, LPHD or other institutions of bamboo management communities can improve bamboo management practices by utilizing practical recommendations to optimize welfare and sustainability.

III. MATERIAL AND METHOD

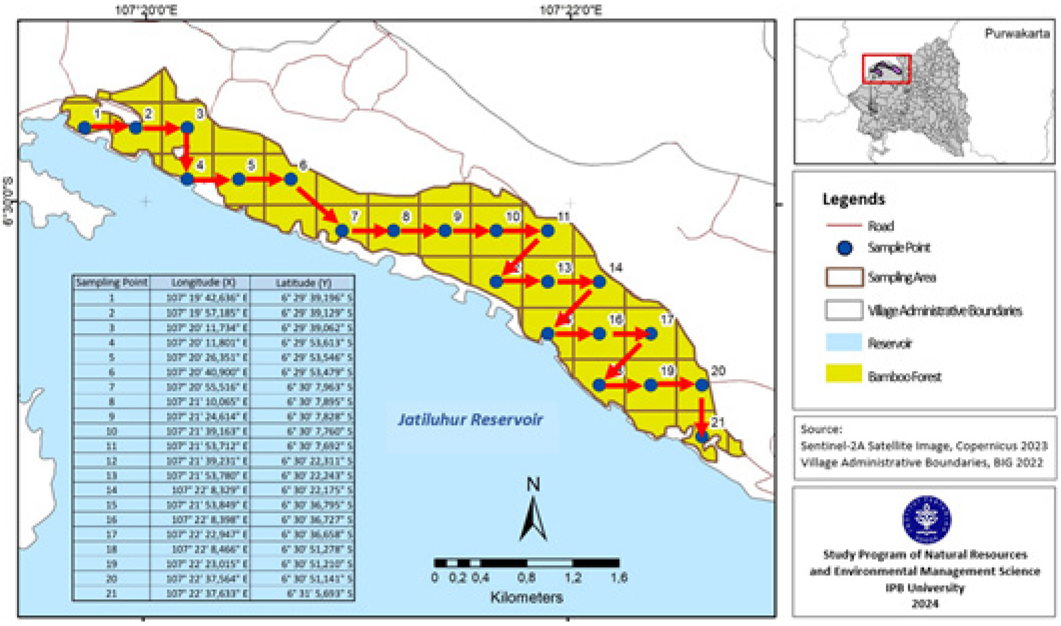
The study was conducted for six months, from January 2024 to July 2024, covering the planning stage, data collection, data analysis, and reporting of results.

A. Study Site

Kutamanah Village Forest was chosen as the research location because it represents the implementation of social forestry with two bamboo management systems: monoculture and mixed. This area is located within the geographical coordinates of approximately 107°18'0" to 107°22'0" E longitude and 6°30'0" to 6°32'0" S latitude, with an altitude between 120 m and 245 m above sea level. The area has a tropical climate with high levels of rainfall around 2,480 mm per year (BMKG, 2025). The temperature of Kutamanah ranges between 22°C and 32°C, providing suitable conditions for bamboo cultivation. Grey Alluvial and Red Latosol types dominate the soil in this area, which supports the growth of various kinds of bamboo.

B. Methods

This study employs a quantitative approach with a comparative descriptive design to evaluate the potential and productivity of bamboo in monoculture and mixed systems in Kutamanah Village Forest, Purwakarta Regency, Indonesia. A systematic sampling method was used by dividing the work area into 21 plots. Vegetation inventory began at Plot 1, then moved eastward and southward until reaching Plot 21 (Figure 1). Following forest inventory standards, the plot was 50×50 m (0.25 hectares) (Supriatna et al., 2021). The sampling intensity was 0.4%, adjusted based on available research resources. After inventory, of the 21 plots, 14 plots were identified as Monoculture Bamboo (BAM), and six plots were classified as Mixed Bamboo (BAX), while one plot was overgrown with pure shrubs, without any stands.



Sampling Point	Longitude (X)	Latitude (Y)
1	107° 19' 42,636" E	6° 29' 39,196" S
2	107° 19' 57,185" E	6° 29' 39,129" S
3	107° 20' 11,734" E	6° 29' 39,062" S
4	107° 20' 11,801" E	6° 29' 53,613" S
5	107° 20' 26,351" E	6° 29' 53,546" S
6	107° 20' 40,900" E	6° 29' 53,479" S
7	107° 20' 55,516" E	6° 30' 7,963" S
8	107° 21' 10,065" E	6° 30' 7,895" S
9	107° 21' 24,614" E	6° 30' 7,828" S
10	107° 21' 39,163" E	6° 30' 7,760" S
11	107° 21' 53,712" E	6° 30' 7,692" S
12	107° 21' 39,231" E	6° 30' 22,311" S
13	107° 21' 53,780" E	6° 30' 22,243" S
14	107° 22' 8,329" E	6° 30' 22,175" S
15	107° 21' 53,849" E	6° 30' 36,795" S
16	107° 22' 8,398" E	6° 30' 36,727" S
17	107° 22' 22,947" E	6° 30' 36,658" S
18	107° 22' 8,466" E	6° 30' 51,278" S
19	107° 22' 23,015" E	6° 30' 51,210" S
20	107° 22' 37,564" E	6° 30' 51,141" S
21	107° 22' 37,633" E	6° 31' 5,693" S

Source:
Sentinel-2A Satellite Image, Copernicus 2023
Village Administrative Boundaries, BIG 2022

Figure 1. Location of Bamboo Forest sampling point, Kutamanah Village Forest, Indonesia

Data was collected through several stages, including image mapping, ground-checking and location validation, vegetation inventory, and environmental and social data collection. In the initial mapping, medium-resolution Satellite Imagery analysis from Google Earth Pro (2023) was carried out to identify land cover and bamboo distribution. Then, the land cover classification was done using a pixel-based digital classification method (unsupervised classification), referring to SNI 7645:2010. Furthermore, the plot location was determined using a GPS device with high accuracy and mapped using GIS software (ArcGIS).

The second step was ground-checking and location validation. This step is taken to validate the conformity between the satellite image and the actual condition in the field. Furthermore, adjustments were made to the plot location with accessibility constraints. The adjusted plot location was taken without reducing the representation of strata.

The third step in this study was vegetation inventory. This was carried out by measuring bamboo clumps (culm amount, circumference, and height of clumps) using a measuring tape at the clump's base and a clinometer for the height of the clump. Bamboo culm measurements were also carried out by counting the number of culms per clump, measuring culm diameter and height, and classifying age based on visual characteristics, including color sheen, sheath condition, surface texture, and the presence of white crust on the surface into mature, young, and bamboo shoots. Additionally, the culm condition was recorded as either intact or damaged.

Next, environmental and social data were collected to explore the physical conditions of the environment, such as land slope and soil type. Other vegetation was also identified, mainly perennial plants with a more than 10 cm diameter and other Non-Timber Forest Products (NTFPs). In-depth interviews were conducted with farmers and the Management Institution of Village Forest (LPHD) members regarding bamboo management and utilization practices, economic activities related to bamboo, and challenges faced in bamboo cultivation and marketing in the Kutamanah Village Forest. Respondents were selected purposively, starting with the chief of LPHD. Bamboo farmers were identified through recommendations by the LPHD chief or encountered in the field during bamboo sampling. A total of 3 LPHD members and seven bamboo farmers were interviewed. The parties, that represented diverse roles within the bamboo value chain, including (1) laborers who primarily harvest bamboo, (2) bamboo farmer who manage and harvest their bamboo, (3) transporter/middleman who own or rent transportation for bamboo logistics, and (4) bamboo wholesalers with direct links to sales outlets (material store).

Implementing steps such as training the research team, testing the measurement instrument, and data triangulation ensured the validity and reliability of this study. All members of the research team and enumerators underwent training on measurement methods, bamboo species identification, and data collection procedures to reduce observer bias. Instruments such as measuring tapes, calipers, and clinometers were calibrated before use. Field trials were conducted on test plots at IPB University to ensure that the instruments functioned properly and the team understood the measurement procedures. Data triangulation was conducted by comparing primary data from the field with secondary data from LPHD Kutamanah and information from the Forestry Services Branch II Purwakarta.

C. Analysis

The data analysis process in this study was carried out using SPSS version 25 and Microsoft Excel. The analysis stages include descriptive statistical analysis, normality test, hypothesis test, calculation of bamboo potential, bamboo productivity, economic potential, and sustainability analysis. Descriptive statistical analysis was carried out by calculating the mean, median, standard deviation, and coefficient of variation for each measurement parameter

Table 1. Normality test of clump and culm data using Kolmogorov-Smirnov Test

Clump	Kolmogorov-Smirnov			Culm	Kolmogorov-Smirnov		
	Statistics	Df	Sig.		Statistics	Df	Sig.
Category	.269	760	.000	Amount	.111	760	.000
Height	.179	760	.000	Diameter	.081	28,147	.000
Circumference	.075	760	.000	Height	.094	28,147	.000

(number of clumps, number of culms, culm height, culm diameter, and others), which was then continued by testing the normality of the data. The normality test used the Kolmogorov-Smirnov test to determine the distribution of the data. Since the data were not normally distributed (Table 1), the non-parametric Mann-Whitney U test was used to compare significant differences between the characteristics of the monoculture system and mixed systems' parameters.

The bamboo productivity and economic potential calculation is based on the number of mature culms ready for harvest per hectare. Then, productivity was multiplied by the market price of bamboo (IDR 5,000 per culm) to estimate the economic contribution per hectare per year. For the bamboo mixed system, due to the unavailability of data on the selling prices of perennial crops, the economic contribution will be estimated based on reference market prices. The calculation is conducted using the following formula:

Economic contribution per hectare per year =
BP × MP .... Formula 1

Note: BP = Bamboo productivity. MP = Market price (Farmer: IDR 2,500, Laborer: IDR 1,000, Middleman: IDR 1,500, Wholesaler: IDR 3,000

The principles of research ethics were followed in this study by asking for informed consent verbally. This is done by explaining the purpose and benefits of the survey to the Management Institution of Village Forest (LPHD) members and bamboo farmers. Their participation in interviews and data collection is based on voluntary willingness. Personal data and sensitive information are kept confidential, and the study results are presented without revealing individual identities.

In this study, researchers faced limitations, especially in the limited number of samples, other environmental variables, and the season and time of data collection. Limited time and resources cause the number of plots in the mixed system to be fewer than in monoculture, which may affect the generalization of the results. Then, factors such as clumps' density (Wirabuana et al., 2021), soil fertility, water availability, and sunlight exposure (the intensity of sunlight reaching the forest floor) were also not analyzed in depth, although they may affect bamboo productivity. In addition, the data collection time was unfortunately carried out two weeks after the primary harvest time, which may have affected the number of mature and young culms inventoried. Most of the mature culms had been harvested, so the proportion of regeneration appeared lower. Additionally, in this study, only bamboo vegetation was harvested. Other plants that Perhutani owns remain unharvested as they are not yet in their harvest cycle. According to local farmers and Forestry Services Branch II Purwakarta members, these plants will only be harvestable in approximately 10 years.

Consequently, this study did not calculate the economic potential of plants other than bamboo. Information on community preferences, market access, and other socio-economic factors was studied to a limited extent, so management recommendations may be less comprehensive. Therefore, the researcher's efforts to overcome these limitations were by analyzing the coefficient of variance and confidence intervals to assess the reliability of the estimates. In addition, field data were supplemented with notes on special conditions that could affect the results, such as previous harvest activities.

IV. RESULT AND DISCUSSION

A. Distribution of Bamboo Cover in Kutamanah Village Forest

Kutamanah Village Forest has a total area of 1,242 hectares. Based on the analysis of medium-resolution satellite imagery from Google Earth Pro (2023) and field surveys, land cover is dominated by the bamboo monoculture system (BAM) and the bamboo mixed system (BAX). The bamboo cover area reaches 425.03 hectares or around 34.22% of the total area (Figure 2). BAM dominates the total bamboo cover with 413.99 hectares, while BAX only covers 11.04 hectares.

The dominance of monoculture bamboo in Kutamanah Village Forest is due to the community's desire to cultivate G*igantochloa apus,* which is considered to have high economic value. In addition to *G. apus*, six other types of bamboo grow naturally, such as *G. verticillata*, *G. atroviolacea*, *G. atter*, *Dendrocalamus asper*, *Bambusa spinosa*, and *B. vulgaris var. vulgaris* and *B. vulgaris var. striata*, although in minimal quantities. The land cover analysis used satellite imagery data in 2018, 2020, and 2023. It also showed that granting management rights to the community in Social Forestry did not significantly change the forest coverage in Kutamanah during 2018-2023 (see Table 2).

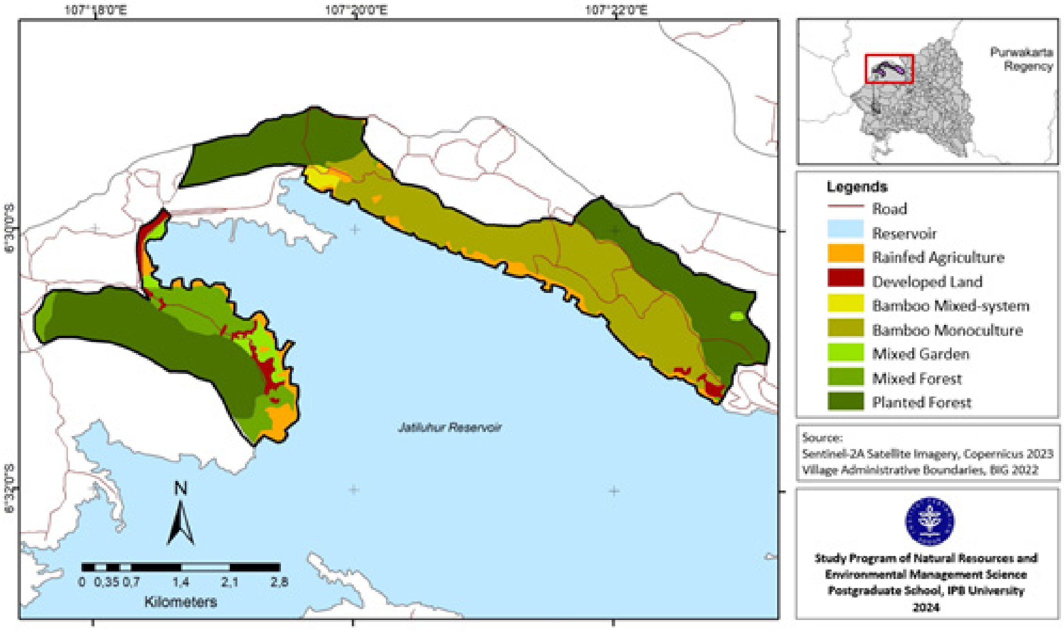


Figure 2. Land cover map of Kutamanah Village Forest in 2024

Table 2. Changes in land cover area of Kutamanah Village Forest in 2018, 2020, 2023

Land Cover	**2018**		**2020**		**2023**	
	Area (ha)	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
BAM	407.08	32.78	415.10	33.42	413.99	33.33
BAX	32.14	2.59	32.14	2.59	11.04	0.89
Mixed Garden	27.67	2.23	29.65	2.39	31.07	2.50
Planted Forest	547.43	44.08	556.18	44.78	556.20	44.78
Mixed Forest	122.84	9.89	106.05	8.54	105.79	8.52
Developed Land	24.84	2.00	28.00	2.25	32.03	2.58
Rainfed Agriculture	80.00	6.44	74.88	6.03	91.88	7.40
Total	1,242.00	100.00	1,242.00	100.00	1,242.00	100.00

Remark: BAM = Bamboo Monoculture System, BAX = Bamboo Mixed System

The data indicates a slight fluctuation in the area covered by monoculture bamboo, increasing from 407.08 hectares in 2018 to 415.10 hectares in 2020, then marginally decreasing to 413.99 hectares in 2023. In contrast, the area under mixed bamboo cultivation significantly declined from 32.14 hectares in 2018 and 2020 to 11.04 hectares in 2023. This shift underscores a growing preference for monoculture systems among the local community.

The social tendency towards monoculture bamboo cultivation is economically motivated. *Gigantochloa apus* is highly valued in the local market due to its suitability for construction materials, rapid growth rate, and short harvest cycles. This aligns with the notion that economic incentives drive communities to practice a monoculture system for immediate financial gains (Belete & Yadete, 2023).

However, the dominance of monoculture systems raises ecological concerns. Monoculture plantations are associated with decreased soil fertility, increased vulnerability to pests and diseases, and reduced biodiversity (Rączkowska, 2019). The significant reduction in mixed bamboo areas suggests a loss of plant diversity, adversely affecting ecosystem resilience and function. Historically, mixed bamboo systems allow bamboo to coexist with hardwood species, contributing to improved soil health, enhanced biodiversity, and diversified income sources (Isukuru et al., 2023; Sulistyono et al., 2018).

The relatively stable forest coverage shows that the social forestry program prevents deforestation effectively. However, the quality of the forest ecosystem may be sacrificed due to the homogenous species. The reduced presence of other bamboo species and hardwoods diminishes habitat complexity, vital for supporting a wide range of flora and fauna (Ekanayake et al., 2021).

B. Differences in Characteristics of Monoculture and Mixed Bamboo Systems

Field inventory was carried out on 21 plots measuring 50×50 meters, consisting of 14 BAM plots and six BAX plots. The measurement results in each plot are presented in Table 3.

The average number of living culms per hectare for BAM is 5,366.2, for BAX is 3,737.8, and for the total area is 4,877.7. The findings highlight significant differences between the characteristics of monoculture and mixed bamboo systems. This research demonstrates that monoculture bamboo demonstrates superior productivity, with more clumps and culms per hectare, larger clump circumference, taller culm height, and greater culm diameter. The findings are consistent with bamboo research in Nepal (Thapa & Aryal, 2012) and applied to different bamboo species (Sharma et al., 2024). These observations provide initial evidence that monoculture systems prioritize bamboo yield.

Table 3. Characteristics of Bamboo Cultivation System

Plot no.	Bamboo cultivation system	Slope (%)	Altitude (m asl)	No. of clumps/ ha	Clump circum-fe-rence (cm)	No. of culms/ ha	No. of culms/ clump	Culm height (m)	Culm diameter (cm)	Other vegetation/ NTFPs
1	Shrubs	-	123	-	-	-	-	-	-	*Cassia fistula, Ficus hispida, Swietenia macrophylla, Kleinhovia hospital*
2	BAX	18	170	144	584	3,760	26.11	7.47	4.34	Shrubs
3	BAM	42	217	196	808	5,694	29.05	9.36	5.82	-
4	BAX	53	148	8	684	384	48.01	8.00	4.36	*Paraserianthes falcataria, Pterocarpus indicus*
5	BAX	78	185	156	723	7,126	45.68	7.30	4.71	Shrubs
6	BAM	60	215	180	693	3,866	21.48	9.09	5.79	-
7	BAX	36	160	128	765	4,862	37.98	8.34	4.94	Shrubs
8	BAM	53	177	180	708	5,391	29.95	9.62	5.15	-
9	BAX	42	205	188	580	5,259	27.98	8.33	4.63	*Dioscorea hispida, Tinospora crispa*
10	BAM	40	220	176	840	8,075	45.88	11.85	5.84	-
11	BAM	55	224	236	643	6,459	27.37	8.58	5.11	-
12	BAM	53	168	192	560	3,527	18.37	11.87	6.06	-

Plot no.	Bamboo cultivation system	Slope (%)	Altitude (m asl)	No. of clumps/ ha	Clump circum-fe-rence (cm)	No. of culms/ ha	No. of culms/ clump	Culm height (m)	Culm diameter (cm)	Other vegetation/ NTFPs
13	BAM	73	243	168	776	6,623	39.42	9.84	5.78	-
14	BAM	45	236	188	732	5,386	28.65	8.64	5.76	-
15	BAM	19	131	116	840	5,916	51.00	11.08	5.91	-
16	BAM	58	172	144	657	4,054	28.15	9.15	5.20	-
17	BAM	27	245	144	721	5,577	38.73	7.21	4.92	-
18	BAM	18	147	168	653	5,266	31.34	9.21	5.22	-
19	BAM	53	149	156	770	4,647	29.79	9.37	5.78	-
20	BAM	38	194	132	751	4,648	35.21	7.70	5.14	-
21	BAX	93	174	44	693	1,036	23.55	9.52	6.51	*Gliricidia sepium, Musa paradisiaca, Manihot esculenta*
Average of Total Area				152.2	709.0	4,877.7	33.2	9.08	5.35	
Average of BAM				169.7	725.1	5,366.2	32.5	9.47	5.53	
Average of BAX				111.3	671.4	3,737.8	34.9	8.16	4.91	

Remark: BAM = Bamboo Monoculture System, BAX = Bamboo Mixed System

Regarding the bamboo management system, the measurement results showed significant differences in the number of clumps, clump circumference, culms, culm height, and culm diameter (Table 4).

The measurement results further confirm the differences in productivity between monoculture and mixed bamboo systems. Monoculture bamboo consistently outperforms mixed systems in almost all key productivity parameters, including the number of clumps, clump circumference, number of culms, culm height, and culm diameter. The higher uniformity observed in monoculture bamboo, as reflected in the lower variability (standard deviation and coefficient of variation), suggests better regulation and resource allocation in this system. These findings emphasize the economic advantage of monoculture systems for communities that prioritize maximizing bamboo yield to meet market demands.

Notably, the number of culms per clump is higher in the mixed bamboo system. This phenomenon may be explained by differences in harvesting intensity and management objectives between the two systems. Monoculture systems, which are typically oriented toward commercial production, often undergo more frequent and uniform harvesting, resulting in a younger clump age structure and limiting the accumulation of culms. In contrast, mixed bamboo systems are generally subject to less intensive or more selective harvesting regimes, allowing culms to persist for extended periods. This accumulation over time contributes to a higher culm density per clump, despite the lower overall productivity observed in mixed systems.

The results of the Mann-Whitney U test showed that the differences were statistically significant ($p < 0.05$) for all parameters measured. Monoculture bamboo had more clumps and culms per hectare and better physical characteristics than mixed bamboo. The monoculture system allocates all available resources solely for bamboo growth. All resources, including space, nutrients, and water, are concentrated on bamboo development, resulting in superior physical characteristics of

Table 4. Comparison of bamboo characteristics between monoculture and mixed systems

Parameters	BAM	BAX	Total Area
The average number of clumps/ha	169.7 ± 15.33	111.3 ± 51.06	152.2 ± 22.07
The average circumference of clumps (cm)	725.1 ± 40.46	671.4 ± 54.63	709.0 ± 34.46
The average number of culms/ha	5,366.2 ± 609.61	3,737.8 ± 1,893.66	4,877.7 ± 782.17
The average number of culms/clumps	32.5 ± 4.48	34.9 ± 7.67	33.2 ± 3.92
The average height of culms (m)	9.47 ± 0.69	8.16 ± 0.58	9.08 ± 0.58
The average diameter of culms (cm)	5.53 ± 0.19	4.91 ± 0.59	5.35 ± 0.26

Remark: BAM = Bamboo Monoculture System, BAX = Bamboo Mixed System
Symbol ± represents 95% Confidence Intervals (CI), calculated using the Confidence function in Excel

Table 5. Results of the Mann-Whitney U Test on the characteristics of monoculture and mixed system bamboo

Variables	Ranks				Test Statistics		
	Bamboo Cultivation System	**N**	**Mean Rank**	**Sum of Ranks**	**Mann-Whitney U**	**Z**	**Asymp. Sig. (2-tailed)**
Height of Clumps	BAM	594	415.21	246,637.5	28,681.5	-8.428	.000
	BAX	166	256.28	42,542.5			
Circumference of Clump	BAM	594	393.35	233,650.5	41,668.5	-3.053	.002
	BAX	166	334.52	55,529.5			
Number of Clumps	BAM	594	364.76	216,664.5	39,949.5	-3.741	.000
	BAX	166	436.84	72,515.5			
Diameter of Culms	BAM	21,122	15,554.57	328,543,522.0	42,918,531.0	-53.229	.000
	BAX	7,025	9,622.40	67,597,356.0			
Height of Culm	BAM	21,122	15,525.12	327,921,485.5	43,540,567.5	-52.422	.000
	BAX	7,025	9,710.95	68,219,392.5			

Remark: BAM = Bamboo Monoculture System, BAX = Bamboo Mixed System, N = sample size,
Z-value = standardized value used to test whether the difference between two groups is statistically significant

the bamboo (Mera & Xu, 2014; Zheng & Pacala, 2024). This indicates that the monoculture system is more effective in increasing bamboo productivity (Table 5).

Despite its advantages in productivity, monoculture systems may face ecological challenges in the long term. The statistical significance ($p < 0.05$) of the differences in all measured parameters underscores the efficiency of monoculture systems in enhancing bamboo yield. However, the ecological benefits of mixed systems—such as increased biodiversity, enhanced pest resilience, and greater ecosystem functionality (Belete & Yadete, 2023)—cannot be overlooked. These results suggest that while monoculture systems offer immediate economic benefits, they might compromise long-term sustainability without strategic interventions.

Field observations revealed that mixed bamboo plots show vegetation diversity, including Albizia, Mahogany, and non-timber forest products such as yam (*Dioscorea hispida*) and bitter vine (*Tinospora crispa*). This vegetation diversity adds ecological value, such as habitat creation and nutrient cycling, which is often limited in monoculture systems.

Furthermore, according to interviews with local farmers, the area, which was previously characterized by a heterogeneous composition of perennial vegetation, provided suitable habitat for a variety of wildlife species, including wild boars (*Sus scrofa*), barking deer (*Muntiacus muntjak*), forest-dwelling birds, and jungle cats (*Felis spp.*). Unfortunately, these species have been reported to have disappeared from the area since the shift toward a landscape dominated by monocultural bamboo stands. This suggests a significant reduction in habitat complexity and ecological niches, which aligns with broader evidence that intensive monoculture can lead to biodiversity loss and an ailing ecosystem (Belete & Yadete, 2023; Rączkowska, 2019). Combining agroforestry practices or a mixed planting system could mitigate the risks while promoting land productivity.

C. Bamboo Potential in Kutamanah Village Forest

The bamboo potential in Kutamanah Village Forest was analyzed to estimate the number of clumps and culms per hectare under monoculture (BAM) and mixed (BAX) systems. Table 6 presents the inventory data, revealing significant variability in the bamboo potential between the two systems. In BAM, the average number of clumps per hectare was 169.7 ± 15.33, while the average number of culms per hectare reached 5,366.2 ± 609.61. Conversely, in BAX, the average number of clumps per hectare was lower, reaching only 111.3 ± 51.05, with an average of 3,737.7 ± 1,893.66 culms/ha. The combined potential across the systems was calculated at 152.2 ± 22.07 clumps/ha and 4,877.7 ± 782.17 culms/ha, indicating the higher productivity of monoculture bamboo.

Table 6. Estimation of clump and culm numbers per hectare based on bamboo cultivation systems

Bamboo Cultivation Systems		Mean	SD	SE	% CV	CI
BAM						
	Clumps/ ha	169.7	29.27	7.82	17.24	± 15.33
	Culms/ ha	5,366.2	1,163.78	311.03	21.69	± 609.61
BAX						
	Clumps/ ha	111.3	63.81	26.05	57.31	± 51.06
	Culms/ ha	3,737.8	2,366.63	966.17	63.32	± 1,893.66
Total Area						
	Clumps /ha	152.2	50.37	11.26	33.09	± 22.07
	Culms/ ha	4,877.7	1,784.71	399.07	36.59	± 782.17

Remark: BAM = Bamboo Monoculture System, BAX = Bamboo Mixed System,
SD: Standard Deviation, SE: Standard Error, CV: Coefficient of Variation, CI: Confidence Interval

Monoculture bamboo shows consistent productivity with lower coefficients of variation (CV) in the number of clumps and culms per hectare. This uniformity is attributed to standardized planting practices and minimal competition from other vegetation, which enhances the efficiency of the monoculture system in regulating bamboo growth (Liu et al., 2018). In contrast, mixed bamboo systems display higher variability (CV values). This increased variability is likely due to other vegetation types, such as Albizia and various non-timber forest products (NTFPs), which, while contributing to ecological diversity, may compete with bamboo for resources. These findings align with another study on *Moso* bamboo (*Phyllostachys edulis*), which indicates that its expansion can intensify intraspecific and interspecific competition, potentially affecting growth dynamics within mixed forest stands (Chen & Bai, 2023).

Recalling that the total area is 425.03 hectares, with a monoculture bamboo area of 413.99 hectares and 11.04 hectares of mixed bamboo, the results of the potential estimation are as follows.

Estimated BAM area	=	70,254	±	6,346	clumps
	=	2,221,553	±	252,372	culms
Estimated BAX area	=	1,229	±	564	clumps
	=	41,265	±	20,906	culms
Estimated total area	=	64,690	±	9,380	clumps
	=	2,073,169	±	332,446	culms

The total potential of bamboo clumps and culms in the study area was estimated by extrapolating inventory data. The monoculture bamboo system, covering 413.99 hectares, was estimated to have 70,254 ± 6,346 clumps and 2,221,553 ± 252,372 culms. In comparison, the mixed bamboo system spanning 11.04 hectares was estimated to contain 1,229 ± 564 clumps and 41,265 ± 20,906 culms. The total bamboo potential in Kutamanah Village Forest was calculated at 64,690 ± 9,380 clumps and 2,073,169 ± 332,446 culms.

These findings demonstrate the trade-offs between the two systems. Monoculture bamboo provides higher productivity that aligns with the economic interests. However, the mixed bamboo offers ecological benefits through complex biodiversity. This supports previous findings from other studies that monoculture systems prioritize economic outcomes whilst mixed systems promote ecological resilience and diversity (Akoto et al., 2020).

Further, the results observed in monoculture bamboo systems support the idea of more predictable yields. However, this system sacrifices ecological diversity by neglecting habitat heterogeneity and soil quality. Conversely, the variability in mixed bamboo systems reflects a more dynamic ecosystem where bamboo coexists with other vegetation, providing additional ecological services such as carbon sequestration, soil stabilization, and habitat provision.

These results emphasize the importance of selecting bamboo management strategies based on short-term economic and long-term ecological sustainability goals. Incentive policies for communities that practice mixed systems may promote diverse vegetation while still meeting their financial needs. This intervention may mitigate the trade-offs between the two cultivation systems.

D. Bamboo Productivity and Economic Contribution

Analysis of the bamboo regeneration rate is essential to assess the sustainability of bamboo forest management. To ensure the regeneration, the ideal proportion of bamboo shoots is around 50% (Rahmadani et al., 2023). However, the results showed that the proportion of bamboo shoots in the Kutamanah Village Forest was relatively low (Table 7).

The shoot proportion can be considered relatively small in the research conducted on the Kutamanah Village Forest, because, based on literature, a proportion below 50% is considered small (Rahmadani et al., 2023). This can be seen from the unbalanced percentage of shoot, young, and mature bamboo. This also happens because data collection occurs two weeks after the primary harvest. Thus, the shoot proportion of this research is only 1.2%. Categorizing mature and young bamboo for inventory is challenging because most mature bamboo has been harvested, significantly affecting the proportion of regenerating bamboo. Thus, for this research, the shoot proportion gained from the proportion of bamboo shoots is 1.0% for BAM, 1.8% for BAX, and 1.2% for the total area.

In the Kutamanah Village Forest, bamboo farmers (consisting of 163 families listed in the 2023 Social Forestry Transformation Decree) are usually assisted by *Pelangsir* (bamboo transporters/middlemen) in bamboo harvesting activities. *Buruh* (bamboo laborers) help middlemen harvest bamboo for a fee of IDR 1,000 per culm, with a length of 6 meters. The bamboo farmers get IDR 2,500 per culm selling price from the middlemen. The middlemen then sold the bamboos to *Bandar* (bamboo wholesalers) for IDR 5,000 per culm. Then *Bandar* will sell for IDR 8,000 per culm to the building material stores, which have become partners in the city. Usually, the stores can sell bamboo at IDR 16,000 to IDR 25,000 per culm.

Bamboo productivity is calculated based on the shoot ratio and the number of mature culms per hectare, considering the selling price of bamboo. Estimating bamboo productivity (BP) can then be calculated to determine the estimated number of culms harvested yearly

Table 7. Proportion of bamboo regeneration in monoculture and mixed systems

Plot Name	Proportion of Bamboo (%)			Plot Name	Proportion of Bamboo (%)		
	Shoot	**Young**	**Mature**		**Shoot**	**Young**	**Mature**
Bamboo Monoculture System				**Bamboo Mixed System**			
Plot 03	1.5	46.2	52.4	Plot 02	0	20.4	79.6
Plot 06	0.1	42.9	57.0	Plot 04	0.8	34.6	64.7
Plot 08	0.9	28.8	70.3	Plot 05	1.6	30.1	68.3
Plot 10	0.7	29.2	70.1	Plot 07	1.7	24.3	74.1
Plot 11	0.5	31.5	68.0	Plot 09	1.3	26.5	72.2
Plot 12	1.7	39.9	58.4	Plot 21	5.7	26.1	68.2
Plot 13	0	21.8	78.2				
Plot 14	0.4	31.9	67.7				
Plot 15	3.9	27.0	69.2				
Plot 16	0.7	19.0	80.2				
Plot 17	1.2	22.5	76.3				
Plot 18	0.7	30.3	69.0				
Plot 19	0	33.5	66.5				
Plot 20	1.3	26.2	72.5				
Average	1.0	30.8	68.3	Average	1.8	27.0	71.2
Total Proportion			Shoot Bamboo		1.2 %		
			Young Bamboo		29.6 %		
			Mature Bamboo		69.1 %		

$BP=(SR(\bar{x}\times MC))$ ....Formula 2

(Modified from Supriatna et al., 2021)

Table 8. Bamboo Productivity in Kutamanah Village Forest

	BAM	BAX
SR (bamboo shoot proportion)	1.0 %	1.8 %
$\bar{x}$ (no. of clumps per ha)	169.7 clumps/ha	111.3 clumps/ha
MC (mature clumps = harvest intensity × no. of culms/ha)	3,756.3 culms/ha	2,616.5 culms/ha
Harvest Intensity	70 %	70 %
Number of culms/ha	5,366.2 culms/ha	3,737.8 culms/ha
BP (Bamboo Productivity)	6,374.4 culms/ha/year	5,241.9 culms/ha/year

Remark: BAM = Bamboo Monoculture System, BAX = Bamboo Mixed System

per hectare. The considerations used are the value of the Shoot Ratio (SR), the average number of clumps per hectare ($\bar{x}$), and the number of mature culms (MC). However, based on bamboo's sustainable harvesting, the harvest intensity ratio will be 70% (Dransfield & Widjaja, 1995). Thus, the MC amount is calculated as the proportion of mature bamboo to the total number of culms. The formula is as follows, and the result is presented in Table 8.

For monoculture, the productivity values are 6,374 culms per hectare per year and 5,242 culms per hectare per year for mixed systems. Considering bamboo prices and those proportions, the estimated economic contribution of bamboo management for each party is presented in Table 9.

The potential economic contribution of BAM and BAX per year is IDR 21,573,151,520. The total numbers show the enormous economic potential of bamboo management in the Kutamanah Village Forest for all stakeholders. However, this potential has not been optimally utilized by the surrounding community. Until now, each bamboo farmer harvests 50 to 100 bamboo stalks per day, with 10-15 days of harvesting each month, so the amount obtained is around 1.25 to 2.5 million IDR per month, or up to 15 million IDR per year.

The economic benefits from bamboo cultivation in the study area remain below its potential. This shortfall is due to communities' limited engagement in optimizing the bamboo sector, particularly among bamboo laborers. A significant proportion of the productive-age population in Kutamanah tends to favor employment in the urban industrial sector, which is perceived to offer more stable income and better social mobility (Riggs et al., 2016). This labor migration aligns with broader rural development patterns in Indonesia and other Southeast Asian regions, where rural youth increasingly abandon agricultural work for factory jobs and service-sector employment in cities (Li, 2014).

Considering the conditions in the field, this can happen because, from the entire supply chain, wholesalers obtain the most significant benefits. Meanwhile, the bamboo farmers and laborers get a more limited proportion of economic benefits. Moreover, the middlemen's role is only controlled by a few people who can transport bamboo from the forest to the bamboo collection area. Not all middlemen act as wholesalers who have access to sell

Table 9. Bamboo Economic Contribution in Kutamanah Village Forest

Stakeholder/Role	**Price/culm (IDR)**	**Economic contribution/ha/year (IDR)**		**Economic contribution/year (IDR)**		
		BAM	**BAX**	**BAM (413.99 ha)**	**BAX (11.04 ha)**	**Total Area (425.03 ha)**
Bamboo Farmers	2,500	15,935,000	13,105,000	6,596,930,650	144,679,200	6,741,609,850
Bamboo Laborers	1,000	6,374,000	5,242,000	2,638,772,260	57,871,680	2,696,643,940
Bamboo Middlemen	1,500	9,561,000	7,863,000	3,958,158,390	86,807,520	4,044,965,910
Bamboo Wholesalers	3,000	19,122,000	15,726,000	7,916,316,780	173,615,040	8,089,931,820
Total	8,000	50,992,000	41,936,000	21,110,178,080	462,973,440	21,573,151,520

bamboo to material stores, but all wholesalers are definitely middlemen. This shows that the community's capital, facilities, finances, access, and social position will affect the economic benefits derived from the bamboo potential in the Kutamanah Village Forest.

Furthermore, field observations revealed that even some bamboo farmers (individuals officially entrusted with managing land under the social forestry scheme) show limited interest in bamboo cultivation. In some cases, these individuals opted to transfer or lease their management rights to third parties in exchange for a lump-sum payment. This behavior is often driven by short-term consumer motivation, such as purchasing motorcycles, mobile phones, or household goods, rather than long-term investments in land-based livelihoods. Similar patterns have been documented in social forestry contexts elsewhere, where poor institutional support and unclear tenure arrangements reduce the incentive for sustainable resource management (Larson et al., 2010; Maryudi et al., 2021). This situation underscores the need for improved economic incentives, targeted training, and market access strategies to enhance community participation in sustainable bamboo management.

In addition, the mixed bamboo system in Kutamanah Village Forest incorporates other perennial tree species such as Albizia, which contribute supplementary economic value. Field observations across six mixed bamboo plots, each measuring 50 × 50 meters, identified 45 Albizia trees, equivalent to a density of 30 trees per hectare. Although these trees are not yet ready for harvest and are expected to reach commercial maturity over the next 10 years, they hold significant long-term value. Based on a local market price for Albizia logs with a diameter of 30–39 cm of IDR 600,000 per mature tree at the farmer level (Forestdigest.com, 2023), the total economic contribution of Albizia per hectare at harvest time is projected at IDR 18,000,000. When distributed over a 10-year harvest rotation, this equates to an annual supplementary economic contribution of IDR 1,800,000 per hectare. While modest compared to bamboo, this figure illustrates the economic diversification and resilience potential of integrating multipurpose tree species in agroforestry systems under community-based forest management.

LPHD's active role as a center in managing and distributing fairer benefits to local communities is significant. Suppose the overall process of optimal bamboo utilization can be made sustainable and fair. In that case, the economic benefits of the Kutamanah Village Forest community can be distributed more broadly and more effectively to its surrounding community, particularly if the total bamboo management uses a monoculture bamboo system. The value of productivity and its implications for economic contribution will undoubtedly be more significant. This is consistent with Isukuru et al.'s (2023) research, which states that the bamboo monoculture system can quickly produce a considerable amount of biomass.

However, some literature suggests that monoculture systems pose risks to ecosystem sustainability. Low biodiversity and a suboptimal proportion of bamboo regeneration can increase vulnerability to pests, diseases, and soil degradation (Belete & Yadete, 2023; Rączkowska, 2019). Mixed systems may be less productive economically, but offer ecological benefits regarding biodiversity and ecosystem functions (Isukuru et al., 2023; Sulistyono et al., 2018).

E. Implications in Social Forestry Management in Kutamanah

Social forestry aims to improve community welfare through sustainable forest management. The finding that monoculture bamboo is more economically productive shows the potential of bamboo as a leading commodity in social forestry. However, monoculture systems can threaten the sustainability of ecosystems due to the low biodiversity and the risk of soil degradation (Isukuru et al., 2023; Sulistyono et al., 2018). Therefore, forest management in social forestry schemes must consider the balance between economic productivity and ecosystem sustainability. Implementing a smart agroforestry system can be a solution that combines the advantages of both systems, increasing productivity while maintaining ecosystem function (Akoto et al., 2020; Octavia et al., 2022b). In addition, the results of this study encourage the government and stakeholders to develop policies that support the diversification of forest commodities and increase community capacity in sustainable forest management.

All management recommendations can be implemented to optimize the balance between economic productivity and ecosystem sustainability, especially those related to agroforestry systems, crop rotation arrangements, community capacity building, and market product diversification or service-sector employment

1. Implementation of a smart agroforestry system

   Integrating monoculture and mixed systems in balanced proportions can increase economic productivity while maintaining ecosystem sustainability (Octavia et al., 2022b). Planting perennial plants and other NTFPs with bamboo can increase biodiversity and ecosystem function while providing an additional source of income for the community (Akoto et al., 2020). Combining bamboo with leguminous plants such as Gamal (*Gliricidia sepium*) can improve soil fertility through nitrogen fixation. Furthermore, the potential for bamboo-based ecotourism can also be further explored, leveraging insights from studies on destination readiness and landscape potential to create value-added experiences that promote conservation and community engagement (Kusumoarto et al., 2017; Rahmafitria & Nurazizah, 2022).

   Some studies encourage smart agroforestry systems to increase economic value (Kumar et al., 2014; Octavia et al., 2022b). To maximize these benefits, a shift towards smart agroforestry practice is crucial. Smart agroforestry is an agroforestry model that integrates silvicultural and agricultural sciences to improve land productivity while ensuring ecological sustainability (Octavia et al., 2022b). It emphasizes applying best practices, including certified seeds and seedlings, SOP-compliant nursery systems, fertilization, pest and disease control, and regular maintenance to optimize plant growth and health. This approach promotes technology-based monitoring and structured planting schemes to improve economic outputs, particularly bamboo and companion crops in mixed systems. Implementing smart agroforestry in social forestry contexts like Kutamanah Village Forest can address underutilization of bamboo plant by enhancing community knowledge, increasing productivity, and encouraging long-term sustainable practices.

2. Crop rotation and clump conservation arrangements

   Conducting planned crop rotations and limiting logging intensity to 50% of the potential can ensure optimal bamboo regeneration (Rahmadani et al., 2023). However, the proportion of young culms in Kutamanah is only 29.6%, so the logging intensity becomes smaller. Increasing the proportion of bamboo shoots and young culms is necessary to ensure future bamboo resources. Clump maintenance and conservation should be undertaken to increase growth rates and ensure bamboo regeneration. Adopting conservation strategies in national parks, such as addressing human behavior in using or maintaining resources, may help enhance the effectiveness of bamboo forest management (Rahmafitria et al., 2024).

3. Product and market diversification

   The development of bamboo derivative products and other NTFP, as well as the modernization of processing technology, has excellent potential to increase added value and community income in the Kutamanah Village Forest. Drawing from successful examples of tourism destination management in protected areas, as well as ecotourism readiness studies, bamboo forests could be positioned as multifunctional landscapes that serve both conservation and tourism purposes (Kusumoarto et al., 2017; Nugroho et al., 2023; Nurazizah & Darsiharjo, 2018; Rahmafitria & Nurazizah, 2022). More comprehensive market access and an efficient supply chain will increase the competitiveness of bamboo products. The potential of bamboo forest ecotourism can also be developed as a community-based educational tourism destination, expanding income sources while introducing sustainable bamboo management. The main challenge is to change people's mindsets and encourage stakeholders to facilitate the adoption of infrastructure and policies that support the optimal use of bamboo and other NTFPs. Moreover, market development and value chain enhancement in social forestry will facilitate access to capital markets (Kumar et al., 2014).

4. Community capacity building in sustainable management

Training and technical assistance to the community on sustainable forest management practices can increase productivity while maintaining ecosystem sustainability (Gunawan & Afriyanti, 2019). In addition, increasing community capacity in services-sector employment, such as ecotourism, is vital to support the diversification of bamboo use. With ecotourism training, the community can develop the potential of bamboo forests as educational tourism destinations offering forest tours, bamboo craft workshops, and promotion of other NTFPs. This will provide new, more diverse sources of income and strengthen public awareness of the importance of environmental sustainability.

5. Institutional strengthening

Strengthening the Management Institution of Village Forest (LPHD) Kutamanah is very important to increase the effectiveness of forest management and community participation. This can be achieved through capacity-building for management, sustainable governance, and Pentahelix collaboration with governments, NGOs, academia, the private sector, and the community. The government can facilitate policies and funding, while the private sector helps expand markets and develop technologies for bamboo products and other NTFPs. NGOs and academics play a role in the training, while the community is taught about sustainable cultivation techniques. This institutional strengthening can also be supported by eliminating overlapping regulations (Nugroho et al., 2023). This support will improve people's welfare and open more comprehensive market access.

V. CONCLUSION

This study shows that the monoculture bamboo system in the Kutamanah Village Forest has higher productivity and economic contributions than the mixed bamboo. The productivity of monoculture is 6,374 culms/hectare/year, and the total economic contribution is

IDR 50,992,000/hectare/year. The numbers are much higher than the mixed system, which only reaches 5,242 culms/hectare/year and IDR 41,936,000/hectare/year. However, monoculture systems face challenges to ecosystem biodiversity, while mixed systems offer more ecological benefits with less economic productivity.

The implications of these findings emphasize the need to balance economic productivity and ecosystem sustainability in the social forestry program. Although monoculture systems are more economically beneficial, the risks to environmental sustainability need to be considered. Implementing smart agroforestry systems, crop rotation arrangements, community capacity building, and product diversification are recommended to balance economic productivity and ecosystem sustainability. The Kutamanah Village Forest may provide sustainable economic and ecological benefits with holistic participatory management.

The findings of this study provide important insights into bamboo forest management in social forestry schemes. Further research is recommended to increase the number and distribution of samples to improve resource management and sustainability effectiveness. An increase in the number of plots and a more even distribution between monoculture and mixed systems will increase the representativeness of the data. Future research may also consider analyzing other environmental and socioeconomic factors to provide a more comprehensive picture of the factors that affect the productivity and sustainability of bamboo management. In addition, long-term research is also needed to evaluate the impact of the implemented management recommendations and monitor changes in productivity and ecosystem conditions.

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