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Contents

ENVIRONMENTAL BEHAVIOUR OF COMMUNITIES AROUND PEATLAND AREA OF PULANG PISAU, CENTRAL KALIMANTAN

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ENVIRONMENTAL BEHAVIOUR OF COMMUNITIES AROUND PEATLAND AREA OF PULANG PISAU, CENTRAL KALIMANTAN. Sustainable peatland management must consider the social, economic, and environmental conditions of surrounding communities. Balancing these three pillars is essential for preserving the peatland's functions, which support the lives of various organisms dependent on the ecosystem. This research focuses on the behaviours of communities around peatlands in the Block C Peatland Management Unit (PMU) in Pulang Pisau Regency, Central Kalimantan. It investigates the social and economic variables influencing environmental behaviour in peatland management and utilization. Employing two methods-Participatory Rural Appraisal (PRA) and survey – this research aims to collect comprehensive data. Data processing is conducted by using tabulation and statistical inference. The PRA includes tools like village historical timelines, transects, seasonal calendars, and livelihood preferences, while the survey uses semi-structured interviews to assess individuals' characteristics, perceptions, and participation in peatland management. The study reveals that villages encounter several challenges, including insufficient agricultural support, susceptibility to flooding, restricted access to clean water, and poorly functioning irrigation systems. Climate change has disrupted the dry season, resulting in lower rubber sap production. The limited availability of land for rice farming and a decreasing interest in forestry products are also significant concerns. The communities must shift their agricultural practice to adapt to climate change. While most respondents acknowledge the ecological importance of peatlands, greater involvement in their management is still needed. This underscores the need to enhance community capacity for peatland restoration and conservation. In conclusion, the findings stress the importance of incorporating social factors into peatland preservation efforts to foster environmental sustainability.

Keywords: Behavior, Central Kalimantan, environment, peatland, Pulang Pisau, and PRA

PERILAKU LINGKUNGAN MASYARAKAT DI SEKITAR KAWASAN GAMBUT PULANG PISAU KALIMANTAN TENGAH. Pengelolaan gambut yang lestari perlu mempertimbangkan keadaan sosial, ekonomi dan lingkungan masyarakat sekitar. Keseimbangan tiga pilar konsep pengelolaan seharusnya diperhatikan, sehingga fungsi lahan gambut dapat bertahan, menjadi pendukung kehidupan beragam organisme yang tergantung pada ekosistem. Penelitian ini bertujuan mendeskripsikan perilaku masyarakat di sekitar lahan gambut pada kesatuan pengelolaan gambut Blok C di Kabupaten Pulang Pisau, Kalimantan Tengah, dengan fokus pada variabel sosial dan ekonomi masyarakat yang membentuk perilaku lingkungan dalam pengelolaan dan pemanfaatan lahan gambut. Penelitian menggunakan dua metode,

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yaitu participatory rural appraisal (PRA) dan survei untuk pengumpulan data. Pendekatan PRA meliputi sejarah desa, transek, kalender musim, dan preferensi mata pencaharian, sedangkan survei menggunakan wawancara semi terstruktur untuk mengukur karakteristik, persepsi, dan partisipasi individu terhadap pengelolaan lahan gambut. Hasil penelitian menunjukkan bahwa semua desa menghadapi kurangnya dukungan pertanian, kerentanan terhadap banjir, kekurangan air bersih dan saluran air yang tidak berfungsi dengan baik. Mereka juga menghadapi keterbatasan lahan untuk mengembangkan pertanian padi, serta semakin berkurangnya produksi atau minat petani terhadap produk-produk kehutanan. Masyarakat harus melakukan adaptasi terhadap perubahan iklim. Walaupun mayoritas responden memahami fungsi ekologis gambut, namun partisipasi dalam pengelolaan lahan gambut masih rendah. Penelitian ini juga mengindikasikan kebutuhan peningkatan kapasitas masyarakat dalam restorasi dan konservasi lahan gambut. Implikasi dari temuan ini menggarisbawahi pentingnya integrasi aspek sosial dalam upaya pelestarian lahan gambut untuk mencapai keberlanjutan lingkungan.

Kata kunci: Gambut, Kalimantan Tengah, lingkungan, perilaku, PRA, and Pulang Pisau

I. INTRODUCTION

Indonesia has the largest peatland area among tropical countries in the world, covering approximately 13.43 million hectares, dispersed on Sumatra Island (5.58), Kalimantan (4.54), Papua (3.01), and Sulawesi (0.024) (Anda et al., 2021; BBSDLP, 2011). Pulang Pisau Regency in Central Kalimantan Province covers 924,520.7 ha Peat Hydrological Area (*Kesatuan Hidrologis Gambut-KHG*), or 94.6% of the regency's total area (Aguswan, 2019). Based on the Decree of the Minister of Environment and Forestry Nomor Sk.129/Menlhk/Setjen/Pkl.0/2/2017, the peat area divided into three Peatland Management Unit (PMU), namely the Kahayan–Kapuas, the Kahayan–Sebangau, and the Kapuas–Mangkutup. However, deforestation has occurred in those areas, for example, it is estimated to reach an average of 2-3% per year in Kahayan-Sebangau PMU. The deforestation rate in the Kahayan–Sebangau KHG in 2016-2017 reached 1,459.5 ha, making it imperative to restore because of their function as sources and purifiers of water (if undisturbed, peatlands can store water up to 0.8-0.9 m^3 per m^3 of peat), coastal protectors, and also the largest carbon storage on earth (Husain & Korbaffo, 2024; Maas et al., 2020). Deforestation and forest degradation are suspected to contribute to an increase in greenhouse gas emissions by about 18% of total overall emissions (Purba et al., 2014). Disasters such as prolonged droughts, forest fires, and floods occur. Prolonged droughts have caused damage to residents' plantation crops (rubber). Fires have led to respiratory health problems and limited transportation modes due to reduced visibility during the haze, which also impacts the economy and the distribution of goods. The area of forest fires in 2019 was 6.604,39 ha (Putri, 2022).

The peat dome restoration and rehabilitation program requires the involvement of social and economic elements (Fadmastuti et al., 2018). The objective is to preserve the health of the peat ecosystem, which requires taking into account any factors that may lead to environmental pollution. Community assessment of environmental quality is a crucial aspect of developing natural resources. Understanding environmental sustainability can become social capital, which, if well-managed, will be a critical factor in the success of planned programs. For sustainability, a structure and natural environmental aspects need to be understood, saved, and preserved, which can be built through the positive attitudes of the individuals living within it (Aladağ et al., 2016). Local wisdom in the form of the community's views, values, and practices correlated to the ecological role of peat (Harrison et al., 2020; Padur et al., 2017) along with the potential pollution, and environmental harm, should be studied and considered carefully.

The assessment of the local community is important because they are not just participants, but the key actors in implementing the restoration activities, which in this study are identified in Pulang Pisau Regency, Central Kalimantan. This research investigates the social and economic variables regarding environmental behaviour in peatland management and utilization using Participatory Rural Appraisal (PRA) and survey methods in local communities. The value system that applies to environmental management can be a supporting or inhibiting factor in management, especially when external influences are introduced that could affect the value system (Ibrahim et al., 2019). This underscores the importance of empowering the local community and making them feel responsible for the success of the restoration activities.

II. MATERIAL AND METHOD

A. Study Site, Location and Materials

This research was done in PMU Blok C Pulang Pisau Regency, part of the Kahayan-Sebangau peatland area of Central Kalimantan Province in 2020 (Figure 1). We chose that area since first, it has a large area of peatland, reaching 94.6% of its total area, and is home to a peat dome, the largest carbon storage area within the ecosystem (Julzarika et al., 2020). The second is that at the time of the research, Pulang Pisau was one of the national targets of the national economic empowerment program due to Covid-19 recovery. For this study, we select four villages, namely Buntoi, Mentaren I, and Kalawa in Kahayan Hilir district, and Pilang in Jabiren Raya district where the community's relationship with the peatland ecosystem is deeply intertwined with their daily lives and cultural practices, using PRA techniques. The use of tools helps capture traditional knowledge and land-use practices, which are crucial for maintaining sustainable management. For instance, indigenous practices like observing the water levels in peatlands during the rainy season are often used to determine the best time for agriculture, and these insights are valuable for restoration efforts.

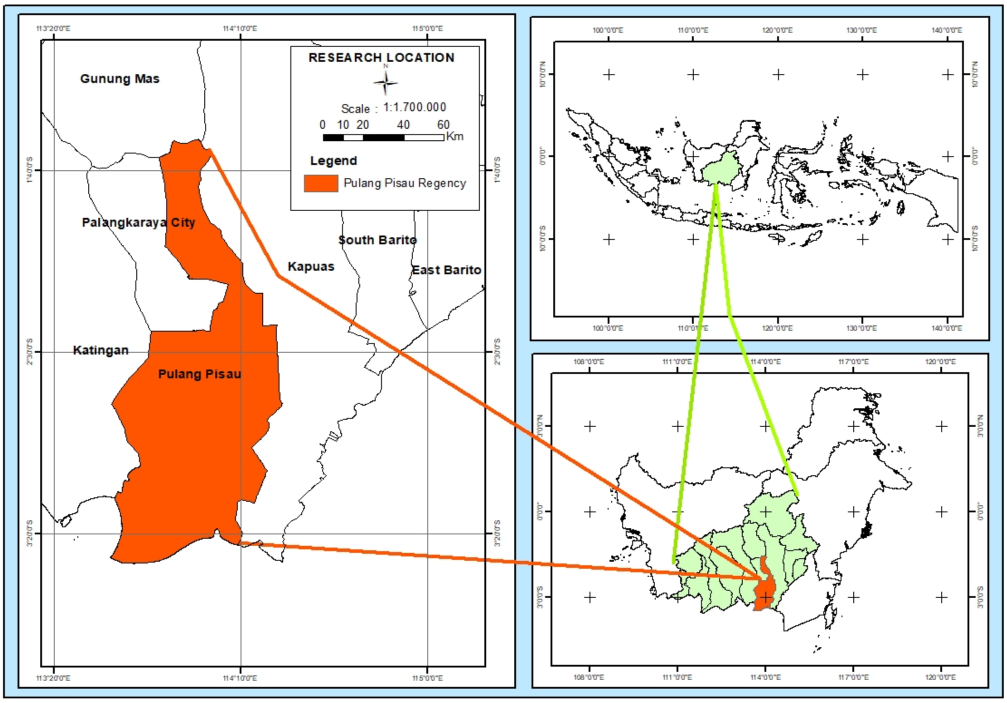


Figure 1. Map of Palangka Raya

We used research materials for conducting PRA, including stationery, cameras, drawing tools, drawing paper, and recording devices. Meanwhile, for the survey, we employed a structured interview set, which included sections on biodata, environmental sanitation, knowledge of peatlands, perceptions of the environmental benefits of peatland, participation in peatland management, and consent to participate in the research).

B. Methods and Analysis

This research applies, first, PRA for the environmental behaviour of communities, after studying its advantages and suitability in revealing environmental management, as it can capture community participation in the research (Berardi, 1998; Mueller et al., 2010). The research employs several data collection techniques, including village historical timeline (Ahmed et al., 2019), walking transect lines (Nyaligwa et al., 2017), seasonal calendar (Shamsuddin et al., 2007), and matrix ranking (Chakraborty et al., 2023; Sanudin et al., 2020).

The second method, the survey, was conducted online. The detailed questions were presented on the Google Forms platform. The respondents were assisted by enumerators to fill out the form using their smartphones. The form was divided into four sections: respondent biodata, knowledge, involvement, and participation in the management and utilization of peatlands. The PRA and survey were conducted in four villages, namely Buntoi, Mentaren I, Pilang, and Kalawa, each characterized by communities that have or are currently relying on peatlands for their livelihoods. The participants of PRA and survey are listed in Table 1):

C. Analysis

The research involved synthesizing quantitative and qualitative information to analyse data collected from PRA and surveys. The specific analysis for each method was conducted because each tool has different processes and objectives (Table 1).

Table 1. Data collection and analyses methods

No	Methods	Objective	How to	Analysis	Number of participants	Reference
1.	PRA					
1.1	Historical timeline	Understand historical context and significant events	Records major historical events in the community that have had significant impacts, such as natural disasters, changes in land use, development projects, or shifts in economic activities.	- Review and categorize events. - Identify trends and correlations. - Create visual representation of events.	18	(Ahmed et al., 2019)
1.2	Walking transect line.	Assess land use patterns and environmental conditions	Gather detailed information about the landscape, environmental conditions, and land use in a specific area by walking through it with community members.	- Review observations and map findings. - Evaluate land use and identify issues. - Integrate community feedback.	17	(Nyaligwa et al., 2017; Yusuf, 2014)
1.3	Seasonal calendar	Investigate seasonal patterns affecting livelihoods and environment	Identify the timing or cycles of various activities, events, and ecological changes throughout the year.	- Examine timing of activities and events. - Identify seasonal challenges and opportunities. - Cross-reference with other data	20	(Shamsuddin et al., 2007)

No	Methods	Objective	How to	Analysis	Number of participants	Reference
1.4	Matrix ranking	Prioritize livelihood options based on community preferences	Record the community preferences regarding livelihood choices for agricultural crops or livestock.	- Compile rankings and identify priorities. - Analyse justifications for scores. - Present findings visually and discuss implications	20	(Chakraborty et al., 2023; Sanudin et al., 2020)
2.	Survey					
2.1	Structured interview	Explore respondent socio-economic characteristics and behaviour.	Online survey using Google platform to assess respondent biodata, knowledge, involvement, and participation in the management and utilization of peatlands.	- Using statistic inference to classify demographic characteristics. - Analyse behaviours on sanitation and waste management. - Using Likert scale to categorize perception towards environmental benefit of peatland and participation on peatland management.	211	(Fauzi et al., 2019; Lutpi, 2016; Salam, 2010; Sugiyono, 2012)

Meanwhile, this research employs a Likert scale to measure public perception and uses a scoring approach to assess community participation. The Likert analysis is used to gauge respondents' perceptions of peatland management and utilisation from an environmental perspective. This analysis involves creating structured and semi-closed questionnaires. These questionnaires are distributed to respondents who meet the criteria of being heads of households and residing in four designated villages. Responses to the questionnaires are recorded on a form that assigns weights to answers, ranging from high to low, or vice versa (Sugiyono, 2012).

Respondent participation in peatland management is measured quantitatively using the same questionnaire employed to assess perceptions. The sample size for measuring respondents' perceptions and participation in peatland management was determined using Slovin's formula. Based on this formula, a minimum target of 204 respondents was set; however, this study successfully gathered information from 211 respondents. The number of respondents exceeded the target due to the use of an online questionnaire via Google Forms, which was distributed for six days by enumerators across four villages. The respondents included farmers, entrepreneurs, private employees, civil servants, students, labours, fishermen, merchants, pensionaries, and part-time teachers (Figure 2). The level of participation in this study is assessed by evaluating the knowledge of the respondents, who are the research subjects, regarding the research topic (Salam, 2010). The participation level analysis uses a scoring approach applied to the questionnaire items. The highest score of 5 indicates high involvement, while the lowest score of 1 indicates low involvement. The data from the questionnaire scoring are summarized in tabular form. To analyse this data, the range value must be calculated by first determining the maximum and minimum values from the questionnaire, followed by calculating the interval value, which is obtained by subtracting the minimum value from the maximum value and dividing the result by three (Fauzi et al., 2019; Lutpi, 2016).

III. RESULT AND DISCUSSION

A. Result

1) PRA

1.1). Village historical timeline

The formation of some villages in Pulang Pisau Regency was started far before the Indonesian independence. In this study, two villages, namely Buntoi and Pilang, were established before 1900. Mentaren I village was established in 1920, Kalawa as the youngest of the fourth villages/Sub-districts, was established in 1958.

Chronologically, the progress of community development in the villages of Buntoi, Mentaren I, Pilang, and the Kalawa Sub-district after their formation can be summarized from the historical timeline in Table 2. From 1970 to 2000, new economic activities like rattan weaving (1970), rubber farming (1978), and efforts to reduce shifting agriculture (1997) were introduced. In the 2000s, canal construction (2006) and bans on slash-and-burn farming (2008) were initiated to improve agriculture and land management. In the last period, 2010-2020, Government aid and infrastructure projects (e.g., rubber, rice, aquaculture) were introduced. Special tourism such as orangutan conservation area, river tracing, *purun* (*Cyperaceae* sp.), and *mandau* crafts were created. It can be highlighted that the

Table 2. Village historical timeline

Year	Events	Challenges
18th century – 20th century	The formation of Buntoi (1700), Pilang (1890), Mentaren I (1920), and Kalawa (1958)	Settlement system that keeps the population from dispersing across the entire village area.
1970	Introduction of rattan weaving in Kalawa	Marketing and the low exchange value of woven products.
1978	Establishment of a joint rubber business group in Kalawa	Stabilizing rubber sap price for farmers' benefit.
1980	Establishment of farmers group	Lack of agricultural support from government.
1990-1991	Severe forest fires that is recurrence in 2014-2015 in Kalawa, 2007, 1997 and 2015 in Pilang, 1997 and 2015 in Mentaren, and 2015 and 2018 in Buntoi.	Eradicate slash-and-burn in land clearing for the agricultural purpose.
1997	The reduction of shifting agriculture practices in Mentaren I	The increasing demand of agricultural lands and input for permanent agriculture system.
2006-2007	Canal construction	Maintenance and upkeep of the canals are required to ensure they work properly.
2008	The governments ban the slash-and-burn practices in Buntoi.	This regulation was reinforced in 2015 and extended to other villages, including Kalawa and Pilang.
2013	Government assistance for providing rubber plant seedling in Mentaren	The governments providing supports for the farmers and the residents in the form of: rubber plant seeds in Mentaren (2013), rice field development in Pilang (2014 and 2017), hand tractor in 2015, fishery in 2017, fruit plant seedlings in 2019 and rice paddy seedlings in 2020.
2014	Rice field development in Pilang, which is reinforced in 2017	The new seedlings were not suitable for the swampy site, and the maintenance techniques were not appropriate.
2015	Hand tractor introduction in Pilang	The farmers must be trained to operate the machines.
2016	Clean water supply and agricultural partnership for rubber sap marketing development in Mentaren I. The establishment of *orang utan* tourism destination in Pilang and *Mandau* art work in Kalawa	The clean water supply system only reaches a small population. The partnership of rubber sap marketing unable to increase the price. *Orang utan* tourism is only open to special interest groups. The *Mandau* crafts only reach a few people because they are produced individually.
2017	Initiation of aquaculture in Mentaren I.	Most of the fish seedlings died or suffered from a lack of food.
2018	The last ritual of traditional dryland paddy plantation ritual in Mentaren I and the introduction of river tourism in Pilang.	The diminishing indigenous agricultural practices. The new form of tourism needs different form of tourism marketing
2019	Government aid for fruit plants seedlings in Mentaren I	The limited parcel of land to accommodate all the new seedling provided.
2020	Government aid for seedlings and other inputs of rice paddy farming in Mentaren I	The irrigation system is not well-organized, making the water supply difficult to manage.

worst situation was happening at the time of the land and forest fire, which occurred in 1990-2019. During that period, the biggest forest and land fires were in 2015 and 2019, which caused a large scale of economic loss and degraded the peatland of Pulang Pisau (Astuti, 2020; Kanyama et al., 2023; Saharjo & Novita, 2022). The best situation occurred in 2010-2020, a period when increasing number of government aid was disbursed for infrastructures, crafts, and tourism.

1.2). Walking transect line

The walking transects conducted across the four villages/urban areas produced types of land use every 100 m and the challenges faced by the communities. The synthesis of land use and the resulting challenges are presented in Table 3. To summarize, the communities face infrastructure limitations for agriculture, such as land shortages and limited knowledge and technology. They also face environmental problems, such as poor sanitation and a lack of clean water, and environmental hazards, such as forest and land fires, flooding, and waste management.

Transect analysis reveals that the community adapts land use to meet their needs. They clustered housing in the village center, developed home gardens near the residential areas, and located community forests farther from the settlement. However, supporting technology for each land use—whether in residential areas, farming, gardens, forests, or fisheries—remains limited and does not function effectively to support environmental sustainability, health, and community welfare.

1.3). Seasonal calendar

The results of the seasonal calendar in the four villages indicate common activities related to the two main seasons, the rainy season and the dry season, as well as the transitions between them. These activities are presented in Table 4. The key events associated with the seasons in the four villages include floods, land and forest fires, and the harvest of crops, dryland paddy, and home garden produce.

The high frequency of forest and land fires has led to climate change in Central Kalimantan. This climate change forces farmers to access productive land that is increasingly farther from residential areas and further into the forest (Marlina et al., 2021). It also shifts the planting pattern such as dryland paddy, and decreases the harvest of commodities such as rubber sap.

1.4). Matrix ranking

The matrix ranking is the process in which the respondents valued the commodities in the everyday livelihood developed in their villages. The preference score is based on respondents' valuation of four aspects: seedlings availability, maintenance easiness, water (irrigation)

Table 3. Walking transect line

Length (m)	Land use	Challenges
0-100	Jetty (Buntoi), housing, livestock (goat) pen, home yard garden mixed with NTFPs.	Population density, limited source of clean water, plastic waste, poor sanitation, seasonal floods, toilet facilities, and waste management are insufficient.
100-400	Housing mixed with NTFPs garden such as rubber plant and fruit plants, and fish ponds.	Population density, plastic waste, poor sanitation, lack of waste collection facilities, seasonal floods, and limited clean water sources. There is some bare land in all villages.
400-800	Dryland farming or garden, rice paddy farming, chicken farm, NTFPs, private rubber forest, shrubs, bare lands, and farmhouse.	Lack of irrigation facilities, irregular plant spacing on garden or private rubber forests, prone to seasonal floods or forest/land fire, dysfunctional canal system, and plastic waste.
800-1.200	Private rubber forest, NTFPs, chicken and swiftlet nest farming mixed with a small housing area.	Lack of irrigation facilities, irregular plant spacing on garden or private rubber forests, prone to seasonal floods or forest/land fire, dysfunctional canal system, poor sanitation and the absence of waste and sewage disposal facilities.

Table 4. Seasonal calendar

Month	Activities or season	Challenges
January - March	Rainy season and the harvesting time of some fruits, such as *durian* and *rambutan*. March is also the last month of rice paddy planting season and usually the harvesting time for dryland paddy.	The residential areas are prone to flooding and facing waste problem.
April-September	Dry season in which the preparation of rubber plantation such as land clearing, bed preparation, and seedling planting are carried out. August is also the harvesting time of rice paddy farming and September is for mango.	The slash-and-burn system for land preparation poses a high risk of causing land and forest fires.
October	Transition of dry season into the rainy season. Usually, this is the seedling time of the rice paddy and the beginning of the planting time for the dryland paddy.	The slash-and-burn system of land preparation for dryland paddy farming increases the risk of farmland fire.
November-December	The beginning and the second month of rainy season. The canal must be cleared in early November to prevent flooding.	Harvesting time of some fruit plants such as *rambutan*, *durian,* and *cempedak* (jack fruit).

Table 5. Matrix ranking

No	Agricultural commodity	Preference score				Challenges
		V.1	V.2	V.3	V.4	
1	Seasonal crops					
1.1	Rice paddy	14	20	16		Irrigation, pest control, and cyclical floods
1.2	Dryland rice		17			Declining interest of farmers
1.3	Cassava		20			Crop failure during dry season
1.4	Vegetable plants				17	Pest control
2	Timber-producing plants					
2.1	Albizia	15	20			Long harvesting age and pest control
3	Non-timber-producing plants					
3.1	Rubber tree (*Hevea brasiliensis*)	14	19	15	20	Cyclical floods and unstable price
3.2	*Rambutan* (*Nephelium lappaceum*)	14			18	Unstable price in harvest season
3.3	*Durian* (*Durio zibethinus*)	16			18	Pest control
3.4	Mango (*Mangifera indica*)	13				Unstable price in harvest season
3.5	*Petai* (*Parkia speciosa*)		20		17	Long dry season
3.6	Rattan (Calamoideae)		20	17		Declining interest of farmers
3.7	Bamboo (Bambusoideae)		20			Unsustainable harvesting
3.8	Palms		20			Declining production
4	Fishery					
4.1	*Patin* fish (Pangasius)	12				Water pollution and marketing
4.2	*Nila* fish (Tilapia)	13				Water pollution and marketing

Remark: V.1 = Buntoi, V.2 = Mentaren I, V.3 = Pilang and V.4 = Kalawa.

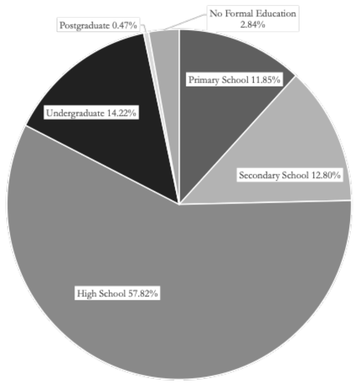
availability, and marketing easiness. Each aspect referred to the easiness or availability, ranging from 1 (very difficult) to 5 (very easy). The sum of preference scores across all commodities for each village is presented in Table 5. The highest score in Buntoi village is the durian home garden. Several commodities score highly in Mentaren I, i.e., rice paddy and cassava farming, albizia, rattan, bamboo, palm forest, and petai home garden. The most preferable commodity in Pilang is rattan. In Kalawa, several commodities are preferred, and the rubber tree achieves the highest score. Aquaculture is only preferable in Buntoi.

2) Survey

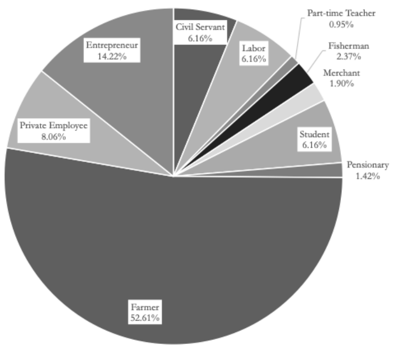
This study successfully gathered data from 211 respondents across four areas: Pilang Village, Mantaren I Village, Buntoi Village, and Kalawa Subdistrict. The distribution of respondents is as follows: 57 in Pilang Village, 52 in Mantaren I Village, 53 in Buntoi Village, and 49 in Kalawa Subdistrict. Most respondents were male, with 118 (55.92%) participants. The majority were within the productive age range (15–64 years), accounting for 205 respondents (97.16%), while the rest (2.84%) were classified as non-productive age. Most of the households had four family members (31.28%). Additionally, food needs were primarily met by purchasing from markets (79.15%), while 18.48% of respondents sourced food from their gardens or fields, and only 2.37% from home yards.

According to the education level, most of the respondents' highest education is high school, with a total of 122 respondents (87.82%), followed by undergraduate and secondary school. There are only 2.84% of the respondents that have not experienced formal education. Based on their livelihood, most of the respondents are farmers, 111 individuals (52.61%). Most residents of the four villages are the indigenous people (Dayak) and engage in similar, often hereditary, livelihoods. The most common income level among respondents is less than USD 31.85 (1 USD = Rp.15,700.00), with 68 respondents (32.23%) falling into this category.

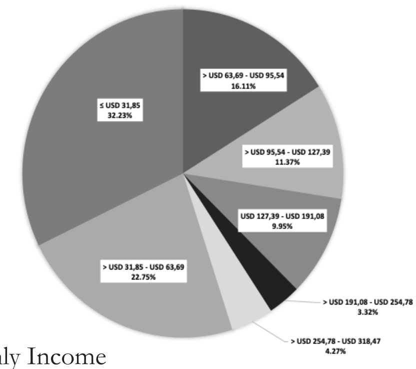
Most of the respondents' residences are more than 3 km from peatlands where they find their livelihoods. Some respondents have huts/shelters in the garden that are used during their farming activities and are also used to protect plants from pests when the plants enter the harvest age. The community has a place to live next to rivers and roads. Some people also live close to the cultivated peatlands. So houses on peatland that have a high thickness have a unique house design, with piles in the foundation (Wardani et al., 2017).



a. Education



b. Occupation



c. Monthly Income

Figure 2. Socio-economic characteristics of the respondents

B. Discussion

1) Lesson learnt form PRA

Currently, most residents live clustered in the center of the villages. Historically, the clustering of the population has occurred in the early formation of villages, at the time, the population was still small, and for security reasons, they lived in groups based on tribe or kinship in the center of the village. Large families initially lived together in one house, called a 'betang'. When the house could no longer accommodate all the family members, they built new houses for each nuclear family, which generally consisted of the father, mother, and their children. This pattern causes people live far apart from their fields, gardens, or forests and causes difficulties in handling emergency hazards such as land and forest fires.

Population growth not only changes the pattern of residence that separates one nuclear family from another nuclear family but also causes expansion of agricultural land to meet their increasing needs. Meanwhile, government assistance to increase farmer capacity and agricultural intensification efforts as an alternative source of income for the communities did not work effectively. This situation encouraged residents to expand land as a new source of income. The expansion of agricultural land contributed to the reduction of peatlands and forest fires.

The severe forest and land fires cause air pollution in the form of fog, threaten community health, and cause significant economic losses in all villages. Although the government has made efforts to encourage community participation in the prevention and management of forest and land fires, low levels of knowledge and limited experience become the major barriers to successful implementation (Fleming et al., 2024). Agricultural extension officers have not yet provided intensive support to farmer groups. Agricultural yields have started to increase since the canals were built. The historical timeline of the villages showed that all villages facing insufficient agricultural support such as infrastructure and advisories, market access, and diminishing indigenous practices such in farming.

From the transect conducted in the four villages, the area from the starting point up to 100 m from the village center is relatively densely populated. Environmental infrastructure issues pose common challenges in the residential area. Residents face limitations in access to clean water, sanitation facilities, and the absence of waste management systems for both household and communal needs. At a medium distance of about 100-400 m from the village center, the land is used for mixed gardens and increasingly sparse residential areas, facing similar environmental problems as those in the village center. The next space consists of agricultural land, plantations, and private forests, with the main issue being the lack of irrigation. In the furthest area, which can extend more than 1,200 m from the village center, there are smallholder rubber forests occasionally mixed with dryland rice fields. Overall, all locations are vulnerable to flooding, lack of clean water, poorly functioning canals, and the absence of waste management systems. Supporting technology for each land use such as residential areas, farming, gardens, forests, and fisheries remains limited and does not work effectively to support environmental sustainability, health, and community welfare. The environmental conditions result in diverse and high levels of pollution, particularly related to water quality, due to their activities as well as activities upstream of rivers (de Jong et al., 2015).

The seasonal calendar depicted challenges related to the cyclical dry season, and rainy season, and the transition between them. The people adapted to the cycle, but nowadays they also face irregularities due to climate change, which is further exacerbating around peatlands (Leng et al., 2019; Marlina et al., 2021). One of the impacts is flooding, which swamps farmland and leads to the risk of crop failure as the canal cannot hold excess water. The price of harvested fruit such as durian, rambutan, kelengkeng, and cempedak tends to decrease during harvesting time. On the other hand, durian production tends to decrease over time as there is no crop rejuvenation system. The fruit harvest season also increases the risk of the attack of monkeys. Another challenge faced by people is the difficulty of irrigation for annual crops during the prolonged dry season due to climate change. The impact is the decreasing harvest of rubber sap. In addition, the prolonged dry season has also resulted in low water levels in the canals which disrupts transportation and delays the movement of goods. Fisheries resources are also threatened as fish that are cultivated in the cage are at risk of dying. This condition shows that climate change makes people difficult to carry out their agricultural activities.

The matrix ranking showed that rice paddy farming was started to be more favored than the old dryland paddy farming. The consequence is that the more demand for rice paddy farmland, the more intensive the technology used and larger the inputs needed such as seedlings, manure, pest controller, and water provided by a proper irrigation system. The irrigation system is also needed for other commodities such as cassava and vegetable plants. The analyses also portray that some forestry commodities such as bamboo, rattan, and palms have faced the problem of diminishing production or declining interest of farmers. A similar phenomenon was also reported by another study, highlighting that the expansion of intensive agriculture such as palm oil plantations reduces the dependency of villagers on forestry-related products (Afentina et al., 2020). The other persistent challenge that was also identified in other analyses is the recurrence of cyclical floods in the rainy season and forest-and-land fires in the dry season.

2) Peatland use and impacts

A total of 127 respondents or 60.19% knew about peatlands and how to use them. In addition, as many as 54% of the respondents stated that they benefited directly from the peatland ecosystem, from agricultural products to handicraft materials. The three largest benefits obtained from peatland are agricultural products, forestry/timber, and fisheries (Figure 3). Agricultural expansion has contributed to the increasing utilization of land surrounding peatlands. Although categorized as marginal land, peatland has the potential to be used for agricultural purposes (Arief et al., 2018). Along with the growth in population around peatlands, the use of peatlands for life fulfillment has increased. In this research, some respondents use peatland to develop agricultural commodities such as rice paddy or dryland paddy fields, seasonal crops, and other root crops. Peatlands used for agricultural and plantation cultivation are generally at depths of less than 300 cm. Peat depths greater than 300 cm are not recommended for cultivation and are better suited for conservation purposes due to the soil's structural instability and low

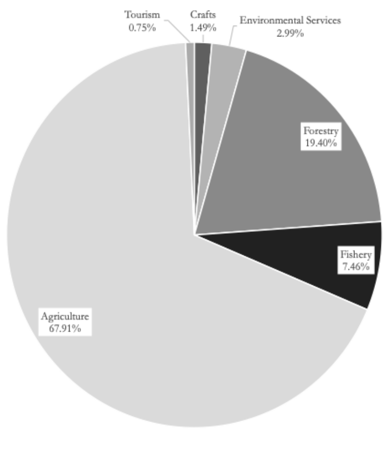


Figure 3. Local benefit from peatland ecosystem

nutrient content (Nasrul, 2010; Wösten et al., 2008; Zamaya et al., 2021).

However, the use of peatland for agriculture and other needs must certainly be approached with caution, as its environmental functions can change. Studies have warned that more intensive, frequent, and large-scale changes in peatland use have occurred over the past hundreds of years (Cole et al., 2022). This survey tried to measure communities' concerns about the environmental impacts of peatland disturbances. Most respondents (71%) perceive that there will be environmental degradation if peatland is damaged. The management of peatland into productive land must pay attention to the condition of peat water management. Poor water management in peatland management to be more productive can result in the oxidation of pyrite (Soewandita, 2018) This oxidation of pyrite results in a further drop in the pH level so it will be very detrimental. Changing the function of peatlands to more productive land without paying attention to peatland characteristics has an impact on environmental quality (Irma et al., 2018; Nugraha et al., 2019). Peatland cultivation must pay attention to the conservation chemistry carried out and is suitable for peatlands. As many as 53% of respondents still do not know how or how to protect, rehabilitate techniques, and peatland restoration techniques so that they are maintained. Some respondents believe that preventing burning is one way not to damage peatlands.

A significant portion of the respondents have already used bottled or gallon water to meet their drinking water needs. A total of 162 respondents (76.78%) reported that they use bottled or gallon water for drinking, as it is easier to obtain and ensures better water quality. Meanwhile, for their bathing, washing, and sanitation (MCK) needs, water is supplied by the local PDAM, as stated by 55 respondents (26.07%). As many as 136 respondents (64.45%) mentioned that the water they use is of good quality, being clear, colourless, and odourless. However, based on the questionnaires distributed to 211 respondents, there is still evidence of the use of river toilets by 70 respondents (33.18%). This condition requires special attention as it can lead to river pollution from domestic waste (de Jong et al., 2015; Fitriansyah et al., 2018).

3) Efforts to achieve peatland sustainable management

This research manages to describe the potential of community engagement in preserving peatland and measure their potential participation in the future (Table 6). The first step is the community acknowledges the importance of peatland in their livelihood. They tend to strongly agree that peatlands serve as carbon storage/absorption areas. The second step is maintaining peatlands functioning for water availability. Most respondents share the same perception regarding the function of peatlands in maintaining water availability, as water will be preserved as long as the peatland remains intact and undamaged.

The third step is keeping peatlands as habitats for various types of plants and specific animals. The fourth step is managing peatlands function as a source of livelihood. The fifth step is the opening of peatlands to make them more productive with zero burning. The community perceives that peatlands have largely been left unused. Regarding the utilization of peatlands, the use of peatlands for timber crops (forestry). They tend to strongly agree with using peatlands for timber crops. Other utilizations are rubber plantations, nature tourism, dryland rice, wetland rice, and lastly, oil palm plantations. The utilization of peatlands for oil palm plantations received the lowest option compared to the other five uses.

The community is aware that the overall condition of peatlands in Central Kalimantan has deteriorated due to converting peatlands into agricultural land by burning. This indicates that some respondents are hesitant about burning peatlands to clear the land. This hesitation is due to the prohibition on burning land for clearing purposes, as well as the sanctions imposed on those who burn peatlands. The community tends to agree that one of the causes of peatland degradation is the construction of poorly designed canals that fail to consider the water table of the peatland. Similarly, the conversion of land use is a cause of peatland damage. The community strongly agrees to conduct conservation/restoration/rehabilitation activities for maintaining the existence of peatlands.

The second part is the assessment of respondent's participation in managing peatland. The involvement of respondents in peatland management activities is one form of community participation, whether active or passive, as a manifestation of their engagement. Community participation in land and forest management plays a crucial role in providing added value to the community (Gunawan &

Table 6. The estimation results of respondents' perceptions using a Likert scale

No.	Question	Likert Index	Category
1	Peatlands act as carbon sinks/stores	83,89	Strongly Agree
2	Peatlands function to maintain water availability	83,70	Strongly Agree
3	Peatlands are habitats for various types of plants and specific animals	85,21	Strongly Agree
4	Peatlands are a source of livelihood/income for the local community	81,90	Strongly Agree
5	Peatlands are opened up for productive activities	80,95	Strongly Agree
6	Peatlands are cleared for paddy farming (wetland rice)	78,10	Agree
7	Peatlands are cleared for dryland rice farming	79,05	Agree
8	Peatlands are cleared for oil palm plantations	57,06	Uncertain
9	Peatlands are cleared for rubber plantations	80,66	Strongly Agree
10	Peatlands are planted with forestry crops (timber)	83,70	Strongly Agree
11	Peatlands are utilized for ecotourism	79,05	Agree
12	Peatlands in Central Kalimantan Province have been damaged	72,80	Agree
13	Peatlands are cleared for farming through burning	53,18	Uncertain
14	Uncontrolled canal construction leads to peatland degradation	76,11	Agree
15	Land use changes are a cause of peatland destruction	74,60	Agree
16	Peatland conservation/restoration efforts are being carried out in this village/area	82,27	Strongly Agree

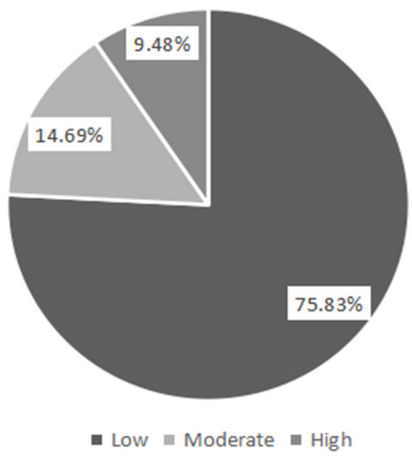


Figure 4. Community participation in peatland management activities

Afriyanti, 2019). Such participation can take the form of labour, ideas, or other resources (Fauzi et al., 2019; Lutpi, 2016; Suhesti & Hadinoto, 2019). A study of the environmental aspects of peat dome restoration and rehabilitation was conducted to assess the level of participation up to the time of this survey. Participation was measured through a survey and then analysed quantitatively.

Based on the figure 4, it is evident that the level of respondent participation in peatland management activities remains low, with 76%, or 160 respondents, not participating. This indicates that most respondents are not involved in peatland management, whether in planning, implementation, utilization, or evaluation. The low level of community participation could suggest that the community is still not engaged in major government programs, particularly those related to peatland management. This result agrees with the low involvement of communities in the peatland rewetting program conducted in Tumbang Nusa Village, Central Kalimantan (Fleming et al., 2024). Research suggested social psychology intervention to increase collaboration and integration between community members in restoration efforts (Brotosuilo et al., 2021). It also stated that peatland restoration actions have to be developed based on ecological, social, and economic principles rather than just limited community knowledge.

Respondents' perception of the role of peatlands as environmental guardians (carbon storage, water, biodiversity) is almost as high as its role as a source of livelihood. Utilization of peatlands also needs to be done more optimally. Although respondents agree that peatlands should be used for cultivating wood and need to be conserved, but they do not participate in managing the peatland. The conversion of peatland to agricultural land still increases. They admit that peatlands are in a damaged condition due to the conversion of peatlands into agricultural land and the construction of canals. Uniquely, this perception is not in line with their involvement in peatland management. It is strongly suspected that the low participation is influenced by economic vulnerability and their capacity to manage peatlands. Vulnerability makes people prioritize the economy over environmental sustainability.

IV. CONCLUSION

This research described the challenges and potential for community participation, both as individuals and groups, in managing the environment around peatlands using PRA (Participatory Rural Appraisal) and socio-economic surveys. This study showed that land use for settlement, agriculture, fisheries, and forestry has been actively passed down through generations. Shifting cultivation, initially practiced with the slash-and-burn technique for land clearing, was phased out in the 2000s due to the recurring forest and land fires that occurred in the 1990s and 2000s. As a result, farming practices turned toward settled agriculture around residential areas, with land being used for farming, home gardens, dryland crops, and forestry, particularly for albazia and rubber trees. However, the insufficient infrastructure and lack of community education on behavioral changes have led to significant environmental pollution around residence areas and agricultural zones, with the risk of contamination spreading to downstream villages. Climate change has altered the timing of, and challenges associated with, the rainy and dry seasons, as well as their transitions. The farmers must modify their planting and harvesting schedules, cope with lower yields, and manage the risk of crop failure from floods or droughts. However, the growing diversity in crops and livelihoods reflects the farmers' ability to adapt to both climate change and the surrounding peatland conditions.

This study also revealed that most respondents rely on market purchases for food, while farming serves as the main occupation, particularly among the indigenous Dayak community. Despite recognizing peatlands' role in carbon storage, water regulation, habitat provision, and livelihood support, community involvement in peatland management remains low, with 76% not participating. This indicates a lack of community integration in government programs for peatland conservation. Enhancing community engagement in peatland restoration may require integrating ecological, social, and economic principles, as well as psychological interventions to strengthen collaboration among community members in this area.

This research has recorded the chronologic history, land use pattern, adaptation to respond to climate change, and livelihood preferences that encompass society behaviour nowadays. However, the research that was done during the prevalence of the Covid-19 pandemic faced the limited participation of informants on PRA. Fortunately, the online survey successfully gathered data and insights from many respondents, providing valuable information that enhanced the analysis. This study directs further research, including strategies to increase community participation in peatland management, environmental quality concerning potential pollution spread along river flows, and water supply technology for household and agricultural irrigation needss.

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PARTICIPATORY SELECTION OF PLANT SPECIES TO ENHANCE THE SUCCESS OF FOREST REHABILITATION IN BULUSARAUNG FOREST MANAGEMENT UNIT

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PARTICIPATORY SELECTION OF PLANT SPECIES TO ENHANCE THE SUCCESS OF FOREST REHABILITATION IN BULUSARAUNG FOREST MANAGEMENT UNIT. The success of forest area rehabilitation requires community involvement. The selection of plant species that are suitable to community preferences will substantially influence the success of rehabilitation efforts. Communities' preferences for specific plant species may increase their willingness to care the plant. This research explored the importance of participatory plant species selection in supporting forest rehabilitation success of Cahaya Tala-Tala Forest Farmers Group (FFG) in the Bulusaraung Forest Management Unit (FMU), South Sulawesi, Indonesia by applying the agroforestry technique. The study employed the participatory rural appraisal approach in one village and involved 50 respondents. The results indicated that the FFG members' preferences for specific plant species were categorized as being in the "affected" stage and positioned at the "preference" stage according to the hierarchy of effects model. The participation of the FFG members in forest rehabilitation activities at the Bulusaraung FMU is categorized as the "partnership" level. The selected multipurpose tree species are expected to substantially contribute to the community's income and help the success of forest rehabilitation activities in Indonesia.

Keywords: Forest rehabilitation, multipurpose tree species, preference, participatory rural appraisal, forest management unit

PEMILIHAN JENIS TANAMAN SECARA PARTISIPATIF UNTUK MENINGKATKAN KESUKSESAN REHABILITASI HUTAN DI KESATUAN PENGELOLAAN HUTAN BULUSARAUNG. Keberhasilan rehabilitasi kawasan hutan memerlukan keterlibatan masyarakat. Pemilihan jenis tanaman yang sesuai dengan preferensi masyarakat akan sangat mempengaruhi keberhasilan upaya rehabilitasi hutan. Preferensi masyarakat terhadap spesies tanaman tertentu dapat meningkatkan kesediaan mereka untuk memeliharanya. Penelitian ini bertujuan untuk mengetahui pentingnya pemilihan tanaman secara partisipatif dalam mendukung keberhasilan rehabilitasi hutan pada Kelompok Tani Hutan (KTH) Cahaya Tala-Tala di Kesatuan Pengelolaan Hutan (KPH) Bulusaraung, Sulawesi Selatan, Indonesia dengan menerapkan teknik agroforestri. Penelitian ini menggunakan pendekatan Participatory Rural Appraisal di satu desa dan melibatkan 50 responden. Hasil penelitian menunjukkan bahwa preferensi anggota KTH terhadap jenis tanaman berada pada tahap "terpengaruh (affected)" dan pada posisi "memilih (preference)" berdasarkan Model Hierarchi of Effect. Partisipasi anggota KTH tersebut dalam kegiatan rehabilitasi hutan di KPH Bulusaraung dikategorikan dalam tingkat "kemitraan". Jenis pohon serbaguna yang dipilih diharapkan dapat berkontribusi besar terhadap pendapatan masyarakat dan membantu tercapainya keberhasilan rehabilitasi lahan di Indonesia.

Kata kunci: Rehabilitasi hutan, jenis pohon serba guna, preferensi, participatory rural appraisal (PRA), Kesatuan Pengelolaan Hutan

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I. INTRODUCTION

The area of degraded forest and land in Indonesia has increased year by year; in 1968, degraded land was reported to be 20 million ha, in 1990, around 40 million ha, and in 2008, an area of 77.8 million ha (Dirjen Pengelolaan Daerah Aliran Sungai dan Perhutanan Sosial, 2011). However, in 2019, the degraded land in Indonesia was reported to have decreased significantly to 14.01 million ha (Dharmawan & Pratiwi, 2023). Forest degradation is mainly caused by illegal logging, forest conversion, expansion of agricultural land, and forest fires.

For decades, many initiatives have been developed by the Government of Indonesia through several programs and policies to reduce the degraded forest and land in Indonesia significantly. Indonesia has had a forest rehabilitation program since 1978 called the Afforestation and Reforestation Program, with a target of 2,500 ha of nurseries. The implementation of afforestation was 300,000 ha, and reforestation was 100,000 ha in 1978-1979 (Fisher et al., 2023). Indonesia has also carried out land and forest rehabilitation covering an area of 2,561,182 ha, in all provinces, during 2006 – 2010 (Handian & Supriyanto, 2012). The main milestone in the government's real action in forest and land rehabilitation activities was the launch of the GNRHL (National Movement for Forest and Land Rehabilitation) Program in 2003 by the Ministry of Forestry, which was targeted to rehabilitate 3.1 million ha of land (inside and outside forest areas) over 5 years (Nawir et al., 2008). The study revealed that for more than three decades, rehabilitation activities were carried out in more than 400 locations in Indonesia. The success of the forest rehabilitation project, generally characterized by active involvement of local communities, as well as the technical interventions used, specifically addresses the ecological causes of forest degradation.

Subsequently, policies and implementation of the forestry sector as part of corrective measures through a rehabilitation program continue to address the challenges of dealing with the impacts of climate change in the forestry sector (Dharmawan & Pratiwi, 2023). In 2019, the area of forest and land that had been rehabilitated was 395,168 ha, including an area of 206,000 ha of conservation areas and protected forests, 1,000 ha of mangrove forests, coasts, swamps, peatlands, and 188,168 ha of community-owned land (Indrajaya et al., 2022). Rehabilitation programs that have been running well include rehabilitation of ex-mining lands carried out by PT Berau Coal (BC), PT Kaltim Prima Coal (KPC), PT Trubaindo Coal Mining (TCM), PT Kitadin (KTD), and PT Kideco Jaya Agung (KJA) in East Kalimantan and PT Multi Tambangjaya Utama (MTU) in Central Kalimantan. Based on the research results in the six locations, the vegetation resulting from the rehabilitation grew well. Within 5 years, there had been improvements in the site as indicated by very low average erosion, decreased surface flow, increased soil infiltration capacity, many wild animals looking for food around the location, and ecosystem regeneration (Sudarmadji & Hartati, 2016). Reforestation with the enrichment planting method has restored hydrological conditions in the waters of Tabunio, South Kalimantan, and Central Java, after the eruption of Mount Merapi (Indrajaya et al., 2022).

Forest land degradation also occurs in the Bulusaraung Forest Management Unit (FMU) area, usually caused by encroachment activities, land conversion, and commodity conversion. There must be efforts to rehabilitate the degraded forest land to restore its function as a buffer for living ecosystems. In this case, Bulusaraung FMU has carried out several forest land rehabilitation activities from 2019 to 2022. The activities were carried out in Laiya Village, covering an area of 150 hectares; Bontomanurung Village, covering an area of 250 hectares; and in Pada Elo Village, covering an area of 1,000 hectares (KPH Bulusaraung, 2024). Many studies reveal that one of the keys to the success of forest rehabilitation is the active engagement of the local community. Their close relationship with the surrounding forest and strong dependency on the forest will determine its success (Parhusip et al, 2019; Murniati et al., 2022; Octavia et al., 2023). In 2021, forest and land rehabilitation were also carried out by Bulusaraung FMU in collaboration with the AFoCO project in Tala-Tala Hamlet, Bonto Manai Village, covering an area of 13 hectares in the form of an agroforestry demonstration plot. The forest rehabilitation activities begin with the community's selection of plant species. Understanding community preferences on plant species, as well as the land suitability, will determine the success of the demonstration plot establishment. It will eventually become a pilot model of participatory land rehabilitation in other areas.

Subsequently, He et al. (2015) state that selecting plant species for forest rehabilitation requires local participation to achieve economic and ecological benefits. The success of plant growth in forest rehabilitation areas significantly hinges on the community's commitment to maintain the plants, as their livelihoods depend on the surrounding natural resources (Grix & Watene, 2022; Fisher et al., 2023). Local community involvement in land rehabilitation has been implemented in various regions, such as Gorontalo, where communities are involved in critical land rehabilitation programs. However, community involvement at the evaluation stage is still low (Suparwata et al., 2016). Similar research was also conducted by Golar et al. (2022) and Mukhlisa et al. (2023) in Central Sulawesi. The research results show that community involvement requires understanding the important meaning or purpose of the activities to be carried out. Community engagement activities in Central Sulawesi did not achieve the expected results because participatory planning only started towards the end of the activity. Martini et al (2016) further stated that intensive cooperation between extension workers and farmers was another important factor that determined the willingness of the community to participate in rehabilitation activities. However, while community preferences in selecting species for forest area rehabilitation are critical to its effectiveness, few studies have been conducted on participatory plant species selection, especially in South Sulawesi.

This research investigated the significance of participatory plant species selection on forest rehabilitation using the agroforestry technique in the Bulusaraung FMU of South Sulawesi. This research is more developed than previous research because there has been community involvement from the beginning of activity planning, activity socialization, selection of plant types and species, plant development and maintenance, and written agreements to ensure that the community is involved until the end of the activity.

II. THEORETICAL FRAMEWORK

The top-down approach in forest management has been proven to fail, particularly in areas where local communities heavily rely on forest resources (Haji et al., 2021; Höhl et al., 2020), such as the communities who settled surrounding the Bulusaraung FMU and at various other regions in Indonesia. Consequently, numerous forest management initiatives fail to achieve conservation and rehabilitation objectives and do not adequately contribute to the income of forest-dependent communities. These failures have exacerbated the difficulties faced by forest-dependent communities, thus prompting governments and other development institutions to involve local communities in forest governance.

In recent decades, community involvement in forest management activities has emerged in many countries as an innovative and promising approach to enhancing the success of forest management. This approach employs a forest rehabilitation strategy encompassing a comprehensive combination of ecological and socioeconomic aspects (Kalonga et al., 2014; Murniati et al., 2022). Many conservation and rehabilitation efforts were undertaken by using agroforestry techniques for sustainable agroecosystem intensification. Sustainable intensification is a process or system in which production is increased without causing detrimental environmental impacts or expanding cultivated land (Pretty and Bharucha, 2014; Parhusip et al., 2019). Forest conservation and rehabilitation initiatives typically begin with selecting plant species based on community preferences and land suitability. Such a selection enhances community participation in managing agroforestry land. Forest rehabilitation activities supported by the community yield sustainable forests and thriving communities. However, the success of various efforts to involve the community in conservation and rehabilitation depends on their willingness to participate. According to Atin et al. (2022), individuals are more likely to engage in an activity if they are assured of receiving benefits. The framework of the research is presented in Figure 1.

The community's willingness to participate in forest rehabilitation activities of the Bulusaraung FMU area was investigated using preference theory, which concerns individuals' choices regarding whether they like or dislike the products (goods or services) consumed. In this study, community preferences are related to selecting plant species for forest rehabilitation activities. The preference of the community on plant species is determined by evaluating various available options, aligning with the perspective of Kotler and Keller (2009), who mentioned that evaluation involves alternative assessment and factor consideration, such as pleasure, satisfaction, fulfilment, and existing benefits. There are six steps in the hierarchy of effect model, namely: (1) Awareness, (2) Knowledge, (3) Liking, (4) Preference, (5) Conviction/intention to buy, and (6) Purchase.

Meanwhile, the extent of community participation in forest rehabilitation efforts was assessed by referencing the participation theory of Arnstein (1969). The ladder of participation from Arnstein (1969) consists of eight steps: (1) manipulation–at this level, the community is not involved because only a few individuals are selected as representatives, and the community is uninformed about the decision-making processes; (2) therapy–at this level, the community begins to be involved but can only receive information about decisions; (3) informing–the government does not hinder participation but only communicates information in one direction without considering people's aspirations; (4) consultation–discussions occur with other stakeholders, but the government decides whether community suggestions and criticisms will be implemented; (5) placation–the government promises to accommodate people's aspirations but secretly adheres to the original plan; (6) partnership–multiparty cooperation is formed to formulate or implement policies and programs; (7) delegation–the community

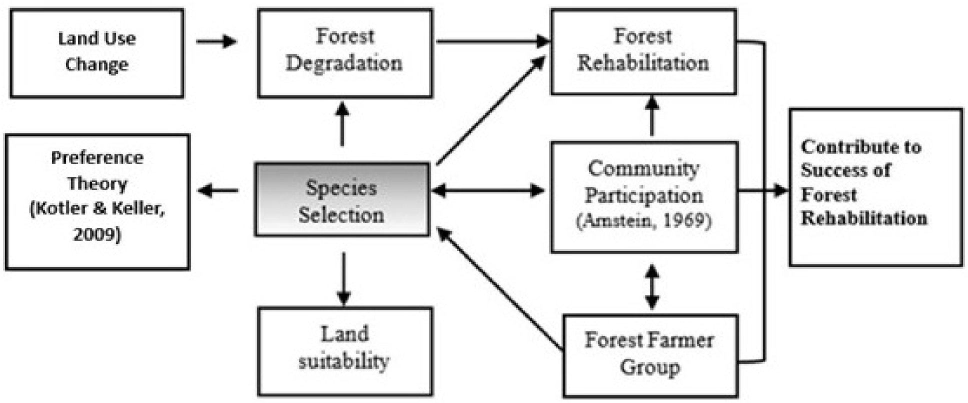

Figure 1. Theoretical framework

has the authority to influence activities, and representatives ensure that the community's voice is considered in the decision-making; and (8) citizen control–community participation is extensive, enabling them to effectively evaluate program/activity performance. Arnstein's participation model encompasses eight levels of participation categorized into three groups: nonparticipation (manipulation and therapy), pseudo-participation (information, consultation, and placation), and genuine community power (partnership, delegated power, and citizen control). This theory was also employed to analyse the social forestry program in Sanggau, Indonesia (Roslinda et al, 2022), and community forest–based management in Gabaldon, Philippines (Gabriel et al., 2017). The Arnstein's ladder of participation is presented in Figure 2.

III. MATERIALS AND METHODS

A. Time and location

The research was conducted over 18 months, from November 2021 to May 2023. The activity occurred in Tala-Tala Hamlet, Bonto Manai Village, Tompobulu Sub-District, Maros District, South Sulawesi Province. This location was chosen because it was a production forest that was burned in 2015, degraded, and yet to be rehabilitated. The construction of the rehabilitation area encompassed an area of 13 ha, geographically situated between the coordinates of latitude 5°5'54.654" S and longitude 119°44' 50.958" E (Figure 3).

The chosen location for the forest rehabilitation plot was an open area resulting from a pine forest fire in 2015. Before rehabilitation, the land was dominated by shrubs, mainly kerinyu (*Chromolaena odorata*) and

Figure 2. The Arnstein's ladder

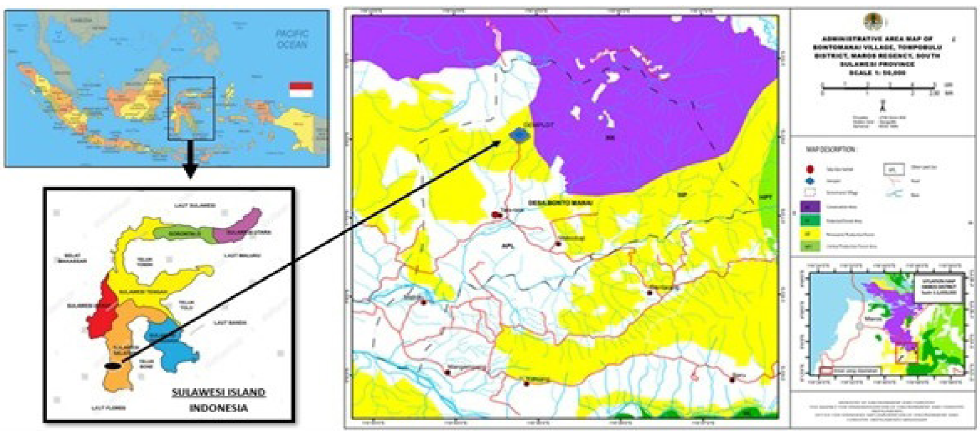

Figure 3. Map of research location

tembelekan (*Lantana camara*). In addition, there were several saplings of pulai (*Alstonia scholaris*) and pine (*Pinus merkusii*). The terrain is relatively flat, with steep slopes and small rivers flowing through the middle. The location lies at an altitude of 250 to 300 m above sea level (asl).

B. Data Collection Methods

Data was collected using mixed methods, or qualitative and quantitative approaches (Widodo et al., 2023) including field observations, questionnaire-based interviews, and focus group discussions (FGD). Field observations assessed the biophysical typology, including vegetation, topography, elevation, and socioeconomic and cultural conditions of the community, including the community participation in forest rehabilitation, which were used to determine the community participation levels based on the Arnstein ladder.

The respondents were selected using a purposive sampling technique. Structured interviews using questionnaires were conducted to gather socioeconomic and cultural data and information on farmers' total income, income contribution from rehabilitation activities, community preferences, and prospects for community involvement in forest rehabilitation activities. Fifty respondents from Bonto Manai Village were interviewed using prepared questionnaires.

In addition, data were collected through a series of FGDs to explore deeper information while validating observations and interview data with prospective participants in the forest rehabilitation site. Three stages of FGD were conducted. The first stage, which involved 50 respondents, aimed to elucidate forest area management issues in the Bulusaraung FMU and discuss factors that affect the success of forest rehabilitation and climate change adaptation and mitigation. The second stage included 26 persons, focusing on community preferences for plant species to be used in forest rehabilitation. The third stage involved 26 people aiming to establish local institutions at the farmer level to manage forest rehabilitation by the Minister of Environment and Forestry Regulation number P.89 in 2018.

C. Analysis

Data analysis was conducted descriptively, qualitatively, and quantitatively using several analytical tools. The analysis employed a system approach (Bahruni et al., 2007), which involved analyzing the components within the agroforestry system and exploring the connections between participation components, types, and species of tree crops cultivated, production, and income, as well as whether these components complement or contradict each other. The data analysis followed an inductive or qualitative approach and focused on deriving meaning rather than generalization.

The stages of data analysis included sociocultural analysis and evaluation of the contribution of community income from forest rehabilitation activities to total income. Sociocultural analysis encompassed several factors: educational level, livelihood, land ownership, and community culture. Data analysis for preference levels was carried out using descriptive analysis that describes the process of selecting plant species taken and chosen by respondents from several species of plants available, with the most appropriate stages of the hierarchy of effect model. Data analysis for participation levels was carried out using descriptive analysis in the form of narratives that connected the conditions of group participation with the most appropriate Arnstein ladder.

Income contribution

The income contribution derived from forest rehabilitation development activities to farmers' total income (on-farm and off-farm) over 1 year was calculated using the formula of Roslinda et al. (2022):

$$\text{Contribution (\%)} = \frac{\text{Income from forest rehabilitation activities (IDR)}}{\text{Total income of household (IDR)}} \times 100\% \quad (1)$$

Community preferences on plant species and participation in forest rehabilitation activities

Assessments and weighting were conducted to determine the plant species preferred by farmers. The criteria for plant species selection were based on four aspects (Reubens et al., 2011), each with several criteria. One of the criteria is the species of plant that is fire-resistant. The forest area around Tala-Tala Hamlet is dominated by pine forests where pine contains flammable resin (Prasetya et al, 2017). This causes the forest area in Tala-Tala Hamlet to be prone to fire during the long dry season. A major fire occurred in 2015, which resulted in around 16 ha of pine forest being severely damaged. So, the criteria for plant species resistant to fire must be considered when selecting the plant species. The plant species chosen by farmers were assessed according to these criteria and proceeded to weight the assessment criteria, as shown in Table 1. In addition, the selected plant species was checked through the Long-Term Management Plan (known as Rencana Pengelolaan Hutan Jangka Panjang, RPHJP) of Bulusaraung FMU.

Triangulation method validated the discussion results (Alfansyur & Mariyani, 2020). The triangulation approach was carried out by combining various methods, data sources, theories, or researchers that increases the credibility and validity of findings.

III. RESULT AND DISCUSSION

A. Result

1. Socioeconomic and cultural typology of society in Tala-Tala Hamlet

Table 2 shows the characteristics of the respondents. The proportion of men was considerably higher than that of women. Gender is important, as both men and women actively participate in land management. Educational level varies from no education to higher school, and the number of uneducated respondents was about half of the educated ones.

The respondents' main occupation is farming. Their average area of wet rice fields is less than 1 ha, and their gardens range from 0.5 to 2 ha. The distance to their residence ranges from 1 to 3 km. The socioeconomic characteristics of the community are important in restoring ecological functions or reducing the damage to the ecology during forest rehabilitation.

The contribution of income obtained from agroforestry development in the forest rehabilitation areas in Tala-Tala Hamlet to the farmers' total income ranged from 1% to 14%, with an average of 4%. This contribution is obtained from the wages of work in the demonstration plot. The plants have not yet contributed to the early stages of planting.

Table 1. Criteria for prioritizing plant species in forest rehabilitation

No.	Assessment aspect	Assessment criteria	Value
1.	Suitable site	Unable to grow	1
		Stunted growth	2
		Grow well	3
2.	Resistant to pests and diseases	Plant dies due to pests and diseases	1
		Plant keeps growing despite many pests and diseases attacks	2
		Plant diseases and pest resistance	3
3.	Resistant to weather and fire	Cannot withstand weather changes and fire	1
		Can withstand weather changes and fire, but its growth is stunted	2
		Can withstand weather changes and fire, still thrive	3
4.	Market prospect	No market prospects	1
		Reasonable price but hard to sell	2
		Reasonable price and easy to sell	3

The number of group members involved in rehabilitation activities was sixteen. Not all group members were eligible for initial land rehabilitation activities; some will be involved later. The total income of the group members ranged from USD 841.1 to USD 3364.5 per year (Table 2). This income was derived from various sectors, including agriculture, livestock, services, trade, and rehabilitation activities. Meanwhile, the income earned by the group members from forest area rehabilitation activities ranged from USD 12.6 to USD 196.3 per year (Table 2).

2. Community preferences on plant species for forest rehabilitation

The preference for certain plant species among the people in Tala-Tala Hamlet reflects the community's attitude toward plant species selection. The research results indicate that several preferred plant species for rehabilitation plots include mahogany (*Swietenia macrophylla*), teak (*Tectona grandis*), red jabon (*Neolamarckia macrophylla*), rambutan (*Nephelium lappaceum*), mango (*Mangifera indica*), durian (*Durio zibethinus*), pomelo (*Citrus maxima*), peanuts (*Arachis hypogaea*), ginger (*Zingiber officinale*), chilli (*Capsicum frutescens*), and corn (*Zea mays*). The

Table 2. Respondent characteristics

Variable	Value
Gender	- Men: 92% - Women: 8%
Educational level	- No education: 32% - Elementary school: 36% - Secondary school: 28% - Higher school: 4% - College: 0
Occupation	Main occupation - Farmer: 90% - Nonfarming: 10% Secondary occupation - Builder labor: 30% - Brown sugar makers: 8% - Trader: 4% - Carpenter: 4% - Resin collectors: 2% - Cattle farmers: 2% - Village officials: 4%
Range of land management (ha)	- Agriculture (private own) land: 0–2 ha household^{-1} - Farm/forest land: 0.5–2 ha household^{-1}
Land distance to the residence (km)	- Agriculture (private own) land: 0.2–2 km - Farm/forest land: 1–3 km
Total income (USD yr^{-1})	- Min: USD 841.1 - Max: USD 3,364.5 - Mean: USD 2,011.6
Income from forest rehabilitation activity (USD yr^{-1})	- Min: USD12.6 - Max: USD 196.3 - Mean: USD 84.1

Note: Number of respondents (variable no. 1–5) = 50 people; number of active respondents in rehabilitation activity (variable nos. 6 and 7) = 16 persons. The exchange rate in December 2021 was USD 1 = IDR 14,267.

Table 3. Weighting results for several species of plants

No	Common name (Species name)	Weighting results				Total value
		Suitable site	Resistance to weather and fire	Resistance to pests and diseases	Market prospects	
1.	Mahogany	3	3	3	3	12
2.	Bungur	3	3	3	3	12
3.	Cashew	3	3	3	3	12
4.	Ginger	3	3	3	3	12
5.	Jabon	3	3	2	3	11
6.	Avocado	3	3	3	2	11
7.	Chili	3	3	2	3	11
8.	Teak	3	2	2	3	10
9.	Tabebuia	3	3	3	1	10
10.	Mango	3	3	2	2	10
11.	Rambutan	3	2	2	3	10
12.	Jackfruit	3	3	2	2	10
13.	Pomelo	3	2	2	2	9
14.	Durian	2	1	3	3	9
14	Corn	3	2	1	3	9
15	Peanuts	3	2	1	3	9
17	Shallots	2	2	2	3	9
19	Rice	3	2	2	2	9
20	Red calliandra	3	-	-	-	-

participatory selection of plant species in the rehabilitation area involves determining priority scales with the community through weighting, as shown in Table 3. The main priority species of forestry plants are 1) mahogany and bungur (*Lagerstroemia speciosa*), 2) red jabon, 3) teak and tabebuia (*Handroanthus chrysotrichus*), and 4) red calliandra (*Calliandra calothyrsus*). The priority scale for MPTS consists of 1) cashew nuts (*Anacardium occidentale*), 2) avocado (*Persea americana*), and 3) mango, rambutan, and jackfruit (*Artocarpus heterophyllus*). Meanwhile, the priorities for annual plants comprise 1) ginger, 2) chilli, and 3) corn, peanuts, shallots (*Allium ascalonicum*), and rice (*Oryza sativa*). Both men and women preferred the annual crops that provide food, as they can be consumed daily by the family members.

Based on the availability of plant seeds and growing requirements (Appendix 1), not all of the plants proposed by the community could be planted in the forest rehabilitation area. Cajuput (*Melaleuca cajuputi*) is one of the proposed plants by Bulusaraung FMU. Based on community preferences on plant species, 52% of them were planted in forest rehabilitation areas, as shown in Table 4.

Table 4. Plant species preferred by the community that planted in the rehabilitation areas

No.	Common name (Species name)
1.	Mahogany
2.	Pine
3.	Red jabon
4.	Cajuput
5.	Rambutan
6.	Mango
7.	Durian
8.	Jackfruit
9.	Red calliandra
10.	Ginger
11.	Chili

3. Group participation in the development and management of forest rehabilitation

In the third stage of FGD, a forest farmers group (FFG) was established and was responsible for planning and managing forest rehabilitation activities in the Bulusaraung FMU. The group was named the Cahaya Tala-Tala FFG, hoping that this group would serve as a role model for the community in Tala-Tala Hamlet.

Candidates for FFG members were selected based on input from the village and the hamlet leader. The selection was based on several criteria, including high motivation to be directly involved in forest rehabilitation activities, gender representation, a shared perception of the benefits of forests, and residence close to the rehabilitation site.

Group formation is crucial to facilitate communication among members and the Bulusaraung FMU. From the selection results, 26 people met the criteria, including twenty-two men and four women. The FFG formation was achieved through deliberation and consensus. The group members elected a chairperson and administrators. They agreed on the group name and work mechanisms. The organizational structure of Cahaya Tala-Tala FFG consisted of 5 administrators (chairman, secretary, treasurer, business section, and cooperation section) and 21 members.

Group participation in the development and management of forest rehabilitation begins from the activity planning stage, which includes selecting plant types and species and creating agroforestry designs. At the planning stage, all group members were actively involved (100%). However, not all group members were consistently involved in the implementation stage, depending on their time availability. Thus, the percentages of the FFG members' involvement in the implementation stage ranged from 19% to 76% (Figure 4).

Although the FFG member participation during the implementation stage did not reach 100%, several members' involvement could be considered as representative of the group. Plant maintenance activities were only carried out by 23% of the group members and were alternated between them. Women and men in the Cahaya Tala-Tala FFG played equal roles at all rehabilitation activities stages, from seedbed nurseries to planting and maintenance. The group processes step by step, not only internally but also externally, with extension workers and FMUs. The group's position, role, and responsibility in maintening of the demonstration plot are written in a cooperation agreement. This proves that group participation in the maintenance of the demonstration plot has reached level 6, i.e., Partnership.

B. Discussion

1. Socioeconomic and cultural typology of society in Tala-Tala Hamlet

Forest rehabilitation requires support from farmer groups that are active, committed, and willing to be directly involved in all stages of forest rehabilitation activities in the Bulusaraung FMU. Therefore, it is necessary to establish an FFG in Tala-Tala Hamlet to manage these

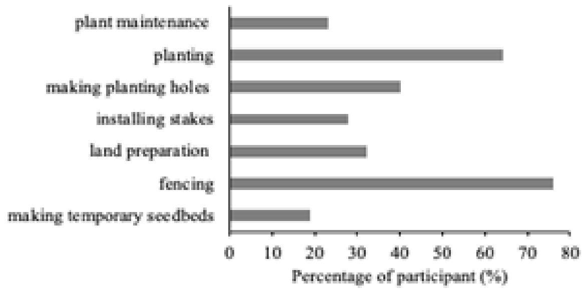

Figure 4. Involvement of the FFG member in the implementation stage of forest rehabilitation

rehabilitation activities. The interview results indicate that some individuals would more actively participate if they could gain an incentive or benefit from the activities. The cooperation and collective community actions in Tala-Tala Hamlet still need to be improved, indicating that social bonding among the community members should be strengthened. The level of trust among the Tala-Tala Hamlet people toward external parties is dynamic and depends on the success of the introduced program activities. When the programs yield actual results, the members' participation increases. This is based on a study by Sabar et al. (2022) in Bulukumba district, which found similar dynamics of the community's trust toward external parties. When external parties, such as an NGO, engage less and do not assist the farmers, the farmers cannot trust them. Conversely, if the farmers receive reasonable assistance, they will have a high level of trust in external parties and will be willing to participate in any activities offered. In the forest rehabilitation activities offered in the research area, the farmers were assisted in preparing an agreement to manage rehabilitation areas to ensure that the community benefits from the outcomes of forest rehabilitation. Consequently, they were motivated to actively participate in all stages of land rehabilitation, including planning, establishing rehabilitation areas, and maintaining the planted plants.

The contribution of income obtained from agroforestry development in the rehabilitation areas in Tala-Tala Hamlet to the farmers' total income ranged from 1% to 14%, with an average of 4%. This contribution was considered low compared to agroforestry's contribution in Nange Mentarep Village, West Kalimantan, Indonesia(Roslinda, Prisila, & Marian, 2023). The low contribution level is attributed to the contribution value only reflecting wages earned from work. This amount will become a benchmark of the success of the work or business, thereby influencing future considerations.

The projected income gained from the forest rehabilitation area in the first year will be from chilli and ginger crops. Further, the community may harvest cajuput leaves and jackfruit in the second year. Later, in the fifth year, all multipurpose tree species (MPTS) are expected to produce fruits or leaves as additional income for the community. This predicted income is expected to contribute to the total household income of group members. Details regarding MPTS, crops planted, and their economic potential are shown in Table 5.

Table 5. Economic value projection of MPTS and crops in the forest rehabilitation area

No.	Plant species	Life cycle (years)	Start of the productive period (years)	Production	Price (USD)	Source
1.	Nutmeg	70–100	3–5	60 kg fruit tree^{-1} yr^{-1}	1.8–2.5 kg^{-1}	Lawalata (2019); Parliansyah et al. (2019); Rawung and Kindangen (2020)
2.	Cajuput	19	2–5	3.97 tons leaves ha^{-1} yr^{-1}	70.1 kg^{-1}	Smith and Idrus (2018); Suhartati and Raharjo (2018)
3.	Durian	100	5–10	100 pcs fruit tree^{-1}	2.5 pcs^{-1}	Ministry of Agriculture (2021)
4.	Mango	50	4–5	200–300 pcs fruit tree^{-1}	1.4–2.1 kg^{-1}	Polosakan, (2016)
5.	Breadfruit	30	3–4	200–700 pcs fruit tree^{-1} yr^{-1}	0.85–1.4 pcs^{-1}	Waryat et al. (2016)
6.	Jackfruit	30	2–5	30–50 pcs fruit tree^{-1}	1.4–3.5 pcs^{-1}	Komarayati (1995); Balamaze et al., (2019)

Tabel 5. Continued

No.	Plant species	Life cycle (years)	Start of the productive period (years)	Production	Price (USD)	Source
7.	Rambutan	30–60	4–8	200–300 kg tree^{-1}	1.1–1.4 kg^{-1}	Arsyadmunir and Ghofur (2019)
8.	Mangosteen	80	5–8	200–500 kg tree^{-1}	1.1–1.8 kg^{-1}	Moniaga et al., (2018); Ministry of Agriculture (2022)
9.	Petai	25	3–4	100 bunches tree^{-1}	1.75 bunches^{-1}	Pujiasmanto, et al. (2022)
10.	Chili	0.5	75 days	13–15 tons ha^{-1}	1.4 kg^{-1}	Nauly (2016); Ministry of Agriculture (2020)
11.	Ginger	1	8–12 months	5.5–8.4 tons ha^{-1}	1.4 kg^{-1}	Gunawan and Rohandi (2018); Sulaehani and Bahrin (2022)

2. Community preferences for plants species

The forest area rehabilitation activities in Tala-Tala Hamlet consider the types of commodities traditionally cultivated by the community and the proposals from the FMU, which are in line with the Bulusaraung FMU's RPHJP. The proposed plant species from the Bulusaraung FMU included mahogany, bungur, pine, red calliandra, candlenut (*Aleurites moluccana*), rambutan, cajuput, upland rice paddy, and porang (*Amorphophallus sp.*).

The community of Bonto Manai Village cultivated various forestry tree species, estate crops, and agricultural commodities through monoculture or mixed cropping patterns (agroforestry). Monoculture crops commonly grown included corn, peanuts, rice, and bamboo (*Bambusa sp.*). Conversely, crops grown through mixed cropping patterns (complex agroforestry) included woody tree species mixed with fruit tree species. Woody tree species included mahogany, teak, jabon, sengon (*Falcataria moluccana*), gmelina (*Gmelina arborea*), kapok (Ceiba pentandra), and wiping fig (*Ficus benjamina*). In contrast, fruit tree species included candlenut, mango, rambutan, starfruit (*Averrhoa carambola*), langsat (*Lansium domesticum*), breadfruit (*Artocarpus altilis*), jackfruit, durian, pomelo, coconut (*Cocos nucifera*), banana (*Musa paradisiaca*), and other food and feed plant species, such as porang, chili, lemongrass (*Cymbopogon citratus*), and elephant grass (*Pennisetum purpureum*).

Based on the Hierarchy of Effect Model (Kotler & Keller, 2009), the Cahaya Tala-Tala FFG members are in the affected area and preference stage. In the affected area, respondents began to feel confident about the certain species of plant they liked and after which it would be used. Meanwhile, at the preference stage, the respondent likes this plant species but does not place it in the main position and still compares it with other species. Hence, the respondent needs a preference position for this species of plant to place the species of plant in an important position compared to other species. At this stage, group members begin to prefer this species of plant over other species (Paz & Vargas, 2023). Community preferences for the species that will be planted in Tala-Tala Hamlet emerge in the alternative evaluation stage in the purchasing decision process, where at this stage, the community is faced with various choices of plant types or species. FFG members' preferences for the species of plants they like are relatively homogeneous, indicating that all group members have the same preferences.

Preference for jabon plant species was mainly due to their rapid growth and short-cutting rotations. Jabon wood reaches a diameter of 30 cm or more within 5 years, making it suitable for timely harvesting and processing (Sarjono et al., 2017). The community also favoured teak and mahogany owing to their high economic value (Raharjo et al., 2016). Furthermore, selecting intercrop types in agroforestry patterns prioritized plant types with economic value, high market demand, ecological benefits, and suitability to local agroclimatic conditions (Prasetyo et al., 2019; Rusyana et al, 2020).

According to the decree of the Ministry of Environment and Forestry no. 23 in 2021, plant species that can be planted for forest rehabilitation in a production forest are woody trees and MPTS, which are suitable for agroclimatic conditions, have economic benefits, and are available in the market (MOEF, 2021). Among the 20 plant species listed in Table 3, some species, such as corn and rice, were not allowed to be planted in the FMU area. These two species require high light intensity for optimal production, thus becoming the main competitor for trees, the primary component of forest rehabilitation (De Oliveira et al., 2016; Nardini et al., 2019). Planting corn on rehabilitated land may hinder the growth of forestry plants. Corn monoculture contributes to soil degradation, characterized by a decline in organic matter content, leading to a decrease in other soil nutrients (Fiorini et al., 2020; Mera et al., 2021).

Red calliandra is planted as a boundary plant on rehabilitated land owing to its numerous benefits, such as functioning as a biofertilizer tree with root nodules that fix nitrogen. Its leaves quickly decompose, enriching the soil with nutrients and releasing allelochemical compounds that inhibit weed growth (Salvator et al., 2020). Furthermore, red calliandra leaves are used for animal feed owing to their high nutrient and energy contents (Franzel et al., 2014; Solomon, 2022). Red calliandra also provides pollen and nectar for bees; honey produced from bees that eat the pollen and nectar of red calliandra has excellent quality (Minarti et al., 2016; Chamberlain, 2000). Furthermore, red calliandra is an erosion-resistant plant on steep slopes (Núñez, 2022). However, red calliandra is an invasive species, so it is necessary to control its reproduction. Research by Yudaputra (2020) indicated that the population of red calliandra is projected to rapidly increase over the next 50 years in Bali Island, emphasizing the need to prevent this vegetation from dominating and posing threats to biodiversity, socioeconomics, and ecosystem health.

Community participation in selecting plant species for rehabilitation activities positively impact their success. Fajri et al. (2024) stated that community participation would increase responsibility in implementing forest and land rehabilitation activities and increase the success of the planting. Community participation in the form of community preferences will strengthen aspects of sustainability and manageability (Budiati & Surtiani, 2015).

3. Group participation in the development and management of forest area rehabilitation

Forest rehabilitation activities require support from farmer groups. Community participation in forest rehabilitation is also essential as it impacts the program's success (Erftemeijer et al., 2022). The group members created their organizational structure as the basis of work division within the organization (Nurlia, 2019), and the structure was completed during the FFG formation.

The participation of group members from the beginning of an activity is crucial, as it increases the group's readiness to carry out activities and programs (Yeny et al., 2018). The Cahaya Tala-Tala FFG shared the common goal of forest rehabilitation by applying agroforestry systems and conducting other forest management activities to preserve the environment and increase the members' income. Forest rehabilitation activities can also improve communal natural resource management because benefits are shared

(Sylviani et al., 2020). The FFG functioned well and was active during the forest rehabilitation activities. Active participation continues until the maintenance stage, aiming to produce products that significantly increase members' income.

To ensure fairness in the implementation of rehabilitation activities, all activities carried out by the group, from planning to implementation, were based on the Agreement of Sustainable Agroforestry Demonstration Plot Management. The agreement outlines the rights and obligations of the group members to plant, maintain, and harvest annual crops and independently market seasonal crops. The annual crop harvest is distributed among the group members managing the land, with 5% allocated to the group treasury. These funds are used for group activities and family members. This demonstrated that the inclusiveness of forest rehabilitation increases the income of the FFG members. This phenomenon also occurred in the FFG of Kampar Regency, Riau Province, as reported by Mohta et al. (2023).

Research findings indicated that community participation in the forest and land rehabilitation activities of the Cahaya Tala-Tala FFG has reached level 6 of Arnstein's participation ladder, i.e., partnership. This is evidenced by the fact that the Cahaya Tala-Tala FFG has gone through several stages of participation: (1) informing–the community received information about planned land rehabilitation activities; (2) consultation–several FGDs were conducted regarding the selection of plant types or species; and (3) partnership–multiparty cooperation was established in formulating policies and programs involving the Cahaya Tala-Tala FFG, the Bulusaraung FMU, the Implementation of Instrument Standardization Unit of Makassar, and the Bonto Manai Village Government. Tripartite collaboration would improve the strength of the FFG and support the success of forest rehabilitation in the Bulusaraung FMU area.

IV. CONCLUSION

The success of the forest area rehabilitation program depends on the community's participation at each stage of the activity. The contribution of income obtained from rehabilitation activities with mixed cropping patterns (agroforestry) in Tala-Tala Hamlet to the total income of the Cahaya Tala-Tala FFG members ranged from 1% to 14%, with an average of 4%. Based on the hierarchy of effects model, the Cahaya Tala-Tala FFG members' preferences for plant species were at the "affected" and the "preference" stages.

The plant species for rehabilitation activities were selected using participatory methods, considering the combination of local commodity plant species, suggestions from Bulusaraung FMU, community choices, and seed availability. The MPTS plants are expected to contribute financially to the local community and support Indonesia's forest rehabilitation.

The Cahaya Tala-Tala FFG's participation in forest and land rehabilitation activities at the Bulusaraung FMU aligns with Arnstein's steps at the "partnership" level. Forest area rehabilitation activities have involved the community, considering their preferences for particular species of plants, to achieve successful rehabilitation efforts. In its implementation, Bulusaraung FMU should take a more active role in providing assistance and offering various incentives to communities actively involved in forest area rehabilitation, enhancing enthusiasm, and fostering a sense of ownership toward the planted vegetation.

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Appendix 1. Plant species and their growth requirements

No.	Plant species	Growth Requirements
1.	Rambutan (*Nephelium lappaceum*)	- Can grow well at an altitude of 1 – 700 m above sea level (asl) - Grows well in sandy or clay soil with a small amount of sand and lots of organic matter - pH between 6 – 6.7
2.	Durian (*Durio zibethinus*)	- Can grow well at altitudes up to 100 - 800 m asl - Rainfall 1500 mm yr^{-1}, pH 6 – 7 - Suitable for sandy loam soil
3.	Mango (*Mangifera indica*)	- Can grow well at altitudes up to 1,300 m asl - Suitable for growing on sandy loam soil - Rainfall 1000 mm yr^{-1}
4.	Nutmeg (*Myristica fragnans*)	- Can grow well at an altitude of 0 – 700 m asl - Rainfall 2000 – 3500 mm yr^{-1}, pH 5.5 – 7 - Suitable for growing on clay to sandy soil
5.	Mangosteen (*Garcia mangostana*)	- Grows well at an altitude of 0 – 800 m asl - Rainfall is around 1250 mm yr^{-1}, pH 5 – 7 - Grows well on red and yellow latosol and podzolic soil types
6.	Breadfruit (*Artocarpus altilis*)	- Grows well at an altitude of 750 – 900 m asl - Rainfall is around 2000 – 3000 mm yr^{-1}, pH 6 – 7 - Grows well on alluvial soil types that contain lots of organic material
7.	Red Jabon (*Neolamarckia macrophylla*)	- Grows well at an altitude of 10 – 1000 m asl - Damp areas
8.	White Jabon (*Neolamarckia cadamba*)	- Grows well at an altitude of 1500 – 3000 m asl - pH 4.5 – 7 - Brown alluvial and podzolic soil types
9.	Cajuput (*Melaleuca cajuputi*)	- Grows well at an altitude of 5 – 450 m asl - Rainfall 1,300 – 1,750 mm yr^{-1} - Grows well on grumusol, latosol and regosol soil types
10.	Mahogany (*Swietenia macrophylla*)	- Grows well at an altitude of 0 – 1500 m asl - Rainfall 500 – 2500 mm yr^{-1} - Grows in slightly clayey soil

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DISTRIBUTION AND HIGH ABUNDANCE OF MEDICINAL PLANTS POTENTIALLY USEFUL IN CANCER TREATMENT FOUND ON THE LAWU MOUNTAIN, INDONESIA

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DISTRIBUTION AND HIGH ABUNDANCE OF POTENTIALLY ANTICANCER MEDICINAL PLANTS IN THE LAWU MOUNTAIN, INDONESIA. Traditional medicines derived from natural resource plants have gained attention since modern medications are expensive for certain diseases, including cancer. The Lawu Mountain ecosystem has shown that the environment supports plant distribution, including species with anticancer properties. This study aimed to determine the distribution and abundance of medicinal plants that could serve as cancer preventives, particularly along the Cemoro Sewu hiking trail. The purposive sample method was employed to make the observations, wherein plots measuring 5 m x 5 m for shrubs and 1 m x 1 m for herbs were created. Plots were made by systematic distribution on both sides of the hiking trail, with four plots at each station. This study had six stations at 2,000 m, 2,200 m, 2,400 m, 2,600 m, 2,800 m, and 3,000 m asl. The distribution of plant species was evaluated using the Morishita index distribution, whereas the abundance of species is observed to get the average value in plant individuals per unit area. Depending on the environmental conditions where the growth occurs, the nine species were found along the hiking track with an abundance ranging from 180 to 4,580 individuals per hectare for the shrub category and 5,000 to 50,830 individuals per hectare for the herbaceous category. The distribution patterns of the species were found to be regular and clumped, respectively.

Keywords: Anticancer medicinal plant, Lawu Mountain, distribution, abundance

DISTRIBUSI DAN KEMELIMPAHAN TUMBUHAN OBAT ANTIKANKER DI GUNUNG LAWU, INDONESIA. Obat-obatan tradisional yang berasal dari tumbuhan alami telah mendapatkan perhatian karena obat-obatan modern memiliki biaya yang tinggi untuk penyakit tertentu termasuk kanker. Ekosistem Gunung Lawu mengindikasikan adanya pola persebaran berbagai jenis tumbuhan, termasuk tumbuhan sebagai kandidat anti kanker. Tujuan riset ini adalah untuk mengidentifikasi keragaman, persebaran, dan kelimpahan tumbuhan dengan potensi sebagai kandidat obat anti kanker, khususnya di lintasan pendakian Cemoro Sewu. Survei dan pengukuran dilaksanakan menggunakan metode purposive sampling dengan membuat plot berukuran 5 m x 5 m untuk tumbuhan perdu serta 1 m x 1 m pada kategori tumbuhan herba. Plot dibuat secara disebar dengan sistematis pada kedua sisi lintasan pendakian, dengan empat kuadrat di setiap stasiun. Stasiun penelitian dibuat mengikuti gradien ketinggian, pada ketinggian 2.000 m, 2.200 m, 2.400 m, 2.600 m, 2.800 m, dan 3.000 m dpl. Keragaman tumbuhan kandidat anti kanker dianalisis secara deskriptif. Pola persebaran tumbuhan obat dianalisis dengan indeks persebaran Morishita dan menghitung kelimpahan jenis tumbuhan yang menunjukkan nilai rata-rata jumlah individu tumbuhan per satuan luas. Kesembilan jenis tersebut ditemukan di sepanjang lintasan pendakian dengan kelimpahan antara 180 hingga 4.580 individu per hektar untuk kategori perdu dan 5.000 hingga 50.830 individu per hektar untuk kategori herba dengan pola penyebaran yang teratur (reguler) serta mengelompok (bergerombol), serta bergantung terhadap kondisi habitatnya.

Kata kunci: Tanaman obat anti cancer, Gunung Lawu, keanekaragaman, distribusi, kemelimpahan

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I. INTRODUCTION

Lawu Mountain ranges from 1.000 m asl to 3.265 m asl in altitude. These conditions enable the growth of various plant species, particularly medicinal plants (Prayoga, 2019; Sugiyarto et al., 2006). Based on Sugiyarto et al. (2006) research, there are 77 species of Cryptogame (Pteridophyte/fern and Bryophyte/mosses) and 50 species of Spermatophyte, which include the Angiospermae and Gymnospermae inhibits on Lawu Mountain. In particular, the medicinal flora comprised 67 species of the total population, including 53 species of Spermatophyta, 13 species of Pterydophyta, and one species of Lichenes (Sugiyarto et al., 2006).

The residents living near Lawu Mountain are tirelessly working towards preserving the knowledge of the local culture and the biodiversity of the mountain environment to maintain the plant population, including medicinal plants (Wibowo et al., 2021). Based on Dai and Mumper (2010), plant species with potential as anticancer agents have certain active compounds. These active compounds can affect proliferation, apoptosis, cell cycle arrest, and angiogenesis, thus preventing tumor growth and spread (Banerjee et al., 2023). Plants can have medicinal properties due to the presence of chemical compounds known as secondary metabolites, which impact specific physiological conditions in the human body. Among the bioactive compounds found in plants are alkaloids, flavonoids, tannins, and phenolic compounds (Nisa et al., 2011).

Commonly, cancer has become a menace in all countries, including Indonesia. In 2008, cancer ranked third as the leading cause of death worldwide after cardiovascular disease and stroke (WHO, 2008). Cancer is a leading cause of death worldwide, accounting for nearly 10 million deaths in 2020 (Ferlay et al., 2021). Therefore, cancer can be recognized as one of the primary threats in the field of health (King & Robins, 2016). The skyrocketing costs and adverse effects of synthetic drugs for cancer treatment are rekindling opportunities for utilizing traditional medicine and natural resources surrounding the residents (Robotin, 2011). This research was a crucial first step in helping communities understand the medicinal properties of plants in their environment over the long term.

Currently, surgical intervention, radiation therapy, and chemotherapy are the primary options for cancer treatment, whereas natural compound ingredients are still considered an alternative treatment supplement (Golbeck et al., 2018). Interestingly, according to Asma et al., 2022 more than 60% of contemporary anticancer drugs, in one form or another, have originated from natural sources. Medications derived from natural compounds are claimed to be more effective for cancer patients compared to synthetic chemical drugs (Atanasov, 2021). To reach our long-term goal, we have been researching to determine the distribution and abundance of potential anti-cancer plant species in Lawu Mountain. This study also describes the potential anti-cancer plant in Lawu Mountain via Cemoro Sewu.

II. STATE OF THE ART AND RESEARCH POSITION

Traditional medical treatment often uses natural resources that have various benefits. According to the WHO (2023), traditional medicine is safer than synthetic medicine. Especially in rural areas, traditional medicine is a culture or habit that uses a potion or therapy that the community has traditionally accepted (Rizvi et al., 2022). Natural products and traditional medicines have diverse contents in the form of chemical structures and biological reactions. According to Yuan et al. (2016), as much as 40% of pharmaceutical products have formulations and essential ingredients extracted from natural ingredients and utilised as traditional medicines. Indonesia is a country with a tropical climate and a very diverse flora. These excesses can be explored as a form of plant utilisation with a chemical structure and biological properties suitable as a medicine or basic treatment ingredient. An example is the experimental process conducted by Soltani et al. (2020), who used *Plantago major* L. to treat cancer mucositis in head and neck patients. The second example is research conducted by Mutiah et al. (2019), who used Ethyl Acetate solvent to extract sabrang onion (*Eleutherine palmifolia*) to treat cervical cancer.

The exploration of flora that has anti-cancer benefits has been carried out in many regions of Indonesia. Table 1 shows various studies conducted, especially the exploration of anti-cancer flora in the Indonesian region, and a comparison of the results of observations in this study.

Table 1. State of the art and research positions

Ref.	Survey region	Data collecting method	The discovered anticancer medicinal plant
Pandiangan et al. (2019)	Sangihe Island, North Sulawesi	Snowball Sampling Method	*Catharanthus roseus*, *Dischidia nythesiana, Artemisia vulgaris* L., *Coleus* sp., *Eleutherine americana Merr., Hibiscus* sp.
Nahdi and Kurniawan (2019)	Southern Slope Merapi Mountain, Yogyakarta	Purposive Sampling with the combination of Snowballing Samping Method	*Cymbopogon citratus* (DC.) Stap
Rahmawati et al. (2020)	Menui Island, Morowali District, Central Sulawesi	Purposive Sampling Method	*Macaranga peltata* (Roxb.), *Abrus precatorius* L., *Sida rhombifolia* L, *Breynia* sp., *Peperomia pellucida* (L.), *Piper betle* L., *Piper nigrum* L., *Cymbopogon citratus* (DC.), *Phymatosorus scolopendria*, *Citrus aurantiifolia*
Batoro and Siswanto (2017)	Poncokusumo district, Malang, East Java P	Snowball Sampling Method	*Calocasia esculentum* Schott., *Ageratum conyzoides* L., *Loranthus* sp., *Calvatia bovista* (L.)., *Curcuma xanthorhiza* L.,
Nugroho et al. (2022)	Lambung Mangkurat Education Forests, South Kalimantan	Cruise Rectangular Method	*Merremia peltate*
Nuraeni et al. (2022)	Rawamerta Region Karawang, West Java	Not Given	*Abrus precatorius* L, *Annona muricata* L., *Curcuma zanthorrhiza* Roxb., *Garcinia mangostana* L.
Arbiastutie et al. (2017)	Gunung Gede Pangrango National Park (West Java, Indonesia)	Clustering Region Sampling	*Cestrum elegans, Clidemia hirta* (L).D.Don, *Lantana camara* L., *Physalis peruviana* L., *Solanum verbascifolium* L., *Stephania venosa* (Blume) Spreng., *Tithonia diversifolia* (Hemsl.) A. Gray
Ammar et al. (2021)	Karst Area of Pacitan District, East Java,	Snowball Sampling Method	*Garcinia mangostana*
Syafruddin et al. (2022)	Dayak Tamambaloh Tribe	Purposive Sampling Method	*Clinacanthus nutans* Lindau, *Annona muricata* L., *Impatiens balsamina* L., *Selaginella doederleinii* Hieron
Pratiwi and Nurlaeni (2020)	Cibodas Botanic Gardens, Indonesia	Not Given	*Sambucus javanica* Blume., *Crinum macowanii* Baker., *Serenoa repens* (W.Bartram) Small,
Present Study	Cemoro Sewu Hiking Trail, Lawu Mountain, Central Java	Purposive Sampling with the Plots Region Method	*Debregeasia longifolia* (Burm. f.) Wedd, *Rubus chrysophyllus* Miq., *Rubus lineatus* Bl., *Rubus fraxinifolius* Poir., *Rubus niveus* Thunb., *Hypericum leschenaultii* Choisy, *Bryonia* sp., *Plantago major* L.

III. MATERIALS AND METHODS

Lawu Mountain is situated between the Central Java and East Java provinces, at 7.63° S and 111.18° E. The top view map of Lawu Mountain is shown in Figure 1. This mountain has an altitude of about 3,265 m asl. Lawu Mountain has several hiking trails but the research was conducted specifically on the Cemoro Sewu hiking trail. The observed sample comprises all plants with potential anticancer content, and the species were clearly defined before the site visit, following the purposive sampling procedure. The survey is conducted alongside the Cemoro Sewu hiking track. The equipment used during the observation process were a camera, field guidebook, scissors, sasak, newsprint, raffia, cutter, labels, herbarium etiquette, and several measuring instruments. The measuring instruments used include the SUNOH 7030 altimeter for assessing the altitude of each observation station, the Luxmeter KRISBOW KW06-288 for measuring radiation intensity, the Hygrometer 45.2007A to measure air humidity, the soil tester TAKEMURA DM-5 for evaluating soil pH acidity, the Canon SX720 HS camera for documenting medicinal plant vegetation, and the GPSMAP 78s for identifying the hiking track to be observed.

The study was conducted on the Cemoro Sewu hiking trail, which various herbaceous plants, shrubs, and trees lushly populated. The research location was divided into six stations following an altitudinal gradient, and plots were made with a systematic distribution on both sides, with four plots per station (Table 2). The determination of this station is based on elevation differences every 200 m asl, ranging from 2000-3000 m asl. It is also based on environmental differences such as lighting, temperature, humidity, and pH, which are stressors of the environment at different altitudes (Ibrahim et al., 2022).

Observation stations I and II entered the mountain zone. However, the subalpine zone dominates Observation Station III to Observation Station VI. In this study, abiotic environmental factors measured include climatic (radiation intensity, air temperature, and humidity) and edaphic (moisture and soil pH), which were noticed and averaged at each station (Table 4).

The measurements of adiabatic environmental factors at the station show a fluctuation; for example, the average light intensity at each station ranged from 10.95×100 lux – to 1317.75×100 lux (Table 2). Based on previous studies, densely vegetated areas, which are areas with low radiation intensity, commonly have wetter moisture in the soil than in open areas (Malinovsky & Krause, 2001). In addition, the temperature differences between each station depended on the population density, season, observation time, and air humidity.

IV. DATA ANALYSIS

Initial screening utilized a list of plant species found in Lawu Mountain, based on the study by Krisanti et al. (2017), which are believed to have anti-cancer properties. The screening revealed that 11 species of plants in

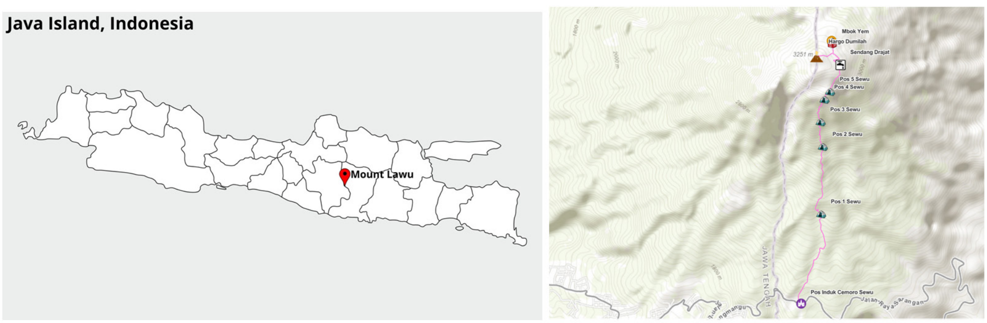


Figure 1. Top view map of Lawu Mountain via Cemoro Sewu

Table 2. An observation station for anticancer medicinal plants on the Cemoro Sewu hiking trail.
Observed station PlotAltitude (m asl)

Observed station	Plot	Altitude (m asl)
I	1	2,064
	2	2,057
	3	2,059
	4	2,066
II	1	2,202
	2	2,209
	3	2,201
	4	2,206
III	1	2,416
	2	2,418
	3	2,423
	4	2,422
IV	1	2,559
	2	2,564
	3	2,572
	4	2,582
V	1	2,800
	2	2,806
	3	2,819
	4	2,821
VI	1	3,000
	2	3,045
	3	3,089
	4	3,092

Table 3. The averaged climatic and edaphic factors of each observed station

Station	Climatic factors			Edaphic factors	
	Radiation intensity (× 100 lux)	Air temperature (°C)	Humidity (%)	Moisture (%)	pH
I	10.95	20.00	73.00	20.00	6.90
II	645.18	27.00	59.50	20.00	7.00
III	30.55	16.25	89.25	-	-
IV	844.50	28.00	54.50	28.75	6.95
V	1317.75	22.50	59.00	32.50	6.80
VI	665.35	19.00	65.25	12.50	6.90

Lawu Mountain were found to be appropriate for the anti-cancer drug, such as *Brasicca juncea*, *Digitalis purpurea*, *Gaultheria leucocarpa*, *Gaultheria nummularoides*, *Melisa axillaris*, *Plantago major*, *Polygonum chinense*, *Solonum nigrum*, *Sonchus asper*, *Sonchus javanicus*, and *Vaccinium varingaefolium*. The purposive sampling method is used to identify the potentially anticancer medicinal plant along the trails. Purposive sampling was frequently used in qualitative research to select participants based on specific criteria (Saini, 2012; Etikan, 2016). Generally, this method did not use random sampling. Instead, it specified sampling criteria to cut off the large amounts of data, resulting in a participant sample representing the population and research objectives (Ames et al., 2019). Furthermore, this method allows for results with comprehensive discussions focused on the research objectives (Saini, 2012). Therefore, this method was suitable for the conducted observations because the Cemoro Sewu Hiking Trail has many non-herbal plant habitats. Purposive sampling is used in qualitative research to select plant samples based on certain criteria (Saini, 2012; Etikan, 2016), by sampling with sampling criteria, namely the height criteria of the sampling location on the Cemoro Sewu Hiking Trail. Therefore, this method does not use random sampling. This method produces a sample of participants that is representative of the population and research objectives (Ames et al., 2019). In addition, this method allows for results with comprehensive discussions that focus on the research objectives (Saini, 2012). Therefore, this method is suitable for the observations made because the Cemoro Sewu Hiking Trail has many non-herbal plant habitats.

In this study, specific criteria for medicinal plants were established at the beginning of the research. Plot selection is based on purposive sampling or the presence of plants with anticancer potential. Plots with 5 m x 5 m were made for shrubs and 1 m x 1 m for herbaceous plants (Osborn, 1950). The plots were spaced 5-10 m from each other. There were six stations (Table 2), each with four plots on both sides of the hiking trail (Barbour et al., 1988).

Table 4. The distribution of observed stations based on altitude

Stations	Altitude (m asl)
I	2,000
II	2,200
III	2,400
IV	2,600
V	2,800
VI	3,000

Identification was based on Backer's (1968) Flora of Java identification book using morphological characters. Observations were made using three analyses: distribution and abundance. The first is a distribution analysis conducted to explain the anti-cancer medicinal plants that were found descriptively. The second analysis remained a distribution analysis. These were intended to determine the distribution of anti-cancer plants on the hiking trail, expressed by frequency at each observation station. Denoted that *Id* represents the Morishita distribution index, with *n* as the species sampling number, *N* as the total species obtained from the observation, and *Xi* as the number of individuals in each sample. The obtained value can be interpreted based on the calculation result. The random distribution is obtained if the *Id*=1, the regular distribution is obtained if the *Id*<1, and the random distribution is obtained if the *Id*>1. The distribution pattern was determined using the Morishita distribution index value with the following equation (Fitriana, 2006):

$$Id = \frac{[(\sum_1^n xi^2) - N]}{N(N-1)} \quad \text{..(1)}$$

The last analysis is considered to be the abundance analysis. Based on this analysis, the average number of individual anticancer plants per unit area was determined. *Di* is considered as the abundance of individuals of the *i*, with *ni* as the number of individual species and the *A* as the sampling area in m^2. The equation is given below.

$$Di = \frac{ni}{A} \quad \text{..(2)}$$

V. RESULT AND DISCUSSION

A. Various of Medicinal Plants with Anti-cancer Potentially in Cemoro Sewu Hiking Trail

Based on research on the hiking trail, eight medicinal plants with the potential to anticancer were found on both sides. The public information considers the species found, and the earlier literature specifically discussed the chemical compound within the anticancer medicinal plant. The specific information is represented in Table 5.

Table 5. The species of anticancer plants along the Cemoro Sewu hiking track

No.	Species	Family	Habitus
1.	*Debregeasia longifolia* (Burm. f.) Wedd	Urticaceae	Shrubs
2.	*Rubus chrysophyllus* Miq.	Rosaceae	Shrubs
3.	*Rubus lineatus* Bl.	Rosaceae	Shrubs
4.	*Rubus fraxinifolius* Poir.	Rosaceae	Shrubs
5.	*Rubus niveus* Thunb.	Rosaceae	Shrubs
6.	*Hypericum leschenaultii* Choisy	Hypericaceae	Shrubs
7.	*Bryonia* sp.	Cucurbitaceae	Herb
8.	*Plantago major* L.	Plantaginaceae	Herb

1. *Debregeasia longifolia (Burm. f.)* Wedd.

Shrub plants have an orientation of upright stems with a height of 5 m. This plant has spiral-shaped and varied leaf arrangements. The upper leaf surface was rough and green, while the lower surface was white-gray. This plant can also produce fruits, and the skin becomes red when the fruit is ripe. According to Rustaman et al. (2000) findings, the *Debregeasias* sp. at the Simpang Mountain West Java contains secondary metabolic, including the alkaloid against the antimitosis characteristic. The advantage of these compounds is that they are better to stop cancer cell growth. The ethanolic leaf extract of *Debregeasia longifolia* has free radical scavenging activity in various oxidation inhibition mechanisms. Glycoside compounds such as saponins, phenols, and flavonoids are also known to inhibit tumor growth. On the other hand, flavonoids are water-soluble antioxidants and free radical scavengers, which can prevent oxidative cell damage and have strong anticancer activity (Radhamani & Britto, 2016). The founded *Debregeasia longifolia* (Burm. f.) Wedd. depicted in Figure 2.

Devi and Chongtham (2016) analyzed the methanol extract of *Debregaesia longifolia* leaves and found that the 1,1-diphenyl-2-picryl hydroxyl (DPPH) radical scavenging activity was 65.41 inhibition, reducing power ability was 1.66 equivalent to ascorbic acid. The total phenol content was 72.11 mg/100 g as catechol equivalent. The flavonoid content was 45.15 mg/100 g as quercetin equivalent; carotene content was 2.56 mg/100 g, and total alkaloids were 18.07 mg/100 g as caffeine equivalent. Therefore, these leaves can support the prevention and cure of inflammatory diseases caused by oxidative stress, such as diabetes, cardiovascular disease, cancer, arthritis, gout, and neurodegenerative diseases.

(a) (b)

Figure 2. Morphology of *Debregeasia longifolia* (Burm. f.) Wedd (a) its habitus, and (b) its fruit

2. Rubus chrysophyllus Miq.

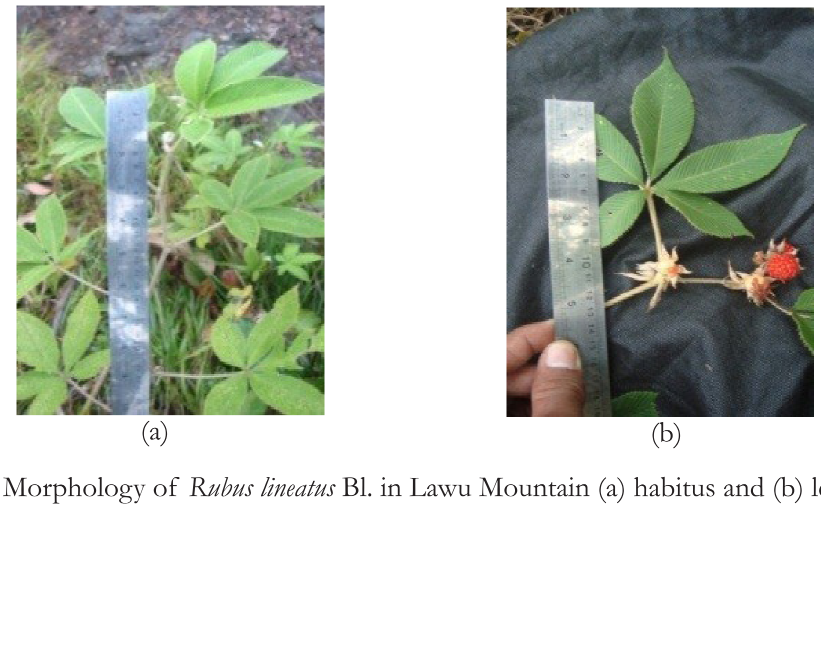
Rubus chrysophytes Miq (Figure 3) is a creeping shrub whose height reaches 5-10 m. This species has a single leaf with a rounded shape resembling a broadened egg. In addition, on the top side there are small bumps. The bottom of the leaf has brown hairy with a leaf venation. With a panicle-type arrangement, the flowers are white, and the fruit is generally pale orange-red. The fruit of *R. chrysophyllus*, which is a dense and attractive-looking aggregate fruit, also has the potential to be developed as an alternative source of consumption fruit from wild plants (Sundarini, 2016). The fruit of *R. chrysophyllus* has the best flavor among the various Rubus species in Java, hence its potential to be cultivated as a table fruit producer (Surya, 2009). According to Bhatt et al. (2023), caffeic acid, m-coumaric acid, and ascorbic acid found in *Rubus* sp. act as an anticancer agent, inhibiting ROS formation and preventing DNA damage and mutation.

3. Rubus lineatus Bl

Rubus lineatus Bl. (Figure 4) had the ability to propagate or creep up along other surfaces or, commonly referred to as a type of shrub vine with a height that could reach 1.5-3 meters. It has a stem with dense hair when it is young and sparsely hairy when it is old. A distinctive silver color was found on the underside of the leaves. This species has orange-red fruits. An extract from Rubus fruits was discovered to potentially inhibit the growth of several human tumour cell lines, such as oral (KB, CAL-27), colon (HT-29, HCT116), breast (MCF-7), and prostate (LNCaP) cells. The study further demonstrated that the extract was effective in causing apoptosis in a COX-2-expressing colon cancer cell line (Bhatt et al., 2023).

(a) (b)

Figure 3. Morphology of *Rubus chrysophytes* Miq. in Lawu Mountain (a) habitus and (b) leaves & flowers



(a) (b)

Figure 4. Morphology of *Rubus lineatus* Bl. in Lawu Mountain (a) habitus and (b) leaves & flowers

4. *Rubus fraxinifolius* Poir

Rubus fraxinifolius Poir (Figure 5) is a shrub with a height of up to 1.5-3 meters. The stems are not covered with waxy white. The leaves are compound with pinnate leaf veins and have 5-9 leaflets. It has a greenish-white flower crown with an egg-round shape and red fruit. At doses ranging from 25 to 200 μg/mL, the berry extracts were assessed for their capacity to suppress the growth of human oral (KB, CAL-27), breast (MCF-7), colon (HT-29, HCT116), and prostate (LNCaP) tumor cell lines. All cell lines showed increased suppression of cell growth with increasing berry extract concentrations, albeit to varying degrees of efficacy. The capacity of the berry extracts to induce apoptosis in the COX-2-expressing colon cancer cell line HT-29 was also assessed (Seeram et al., 2006).

5. *Rubus niveus* Thunb.

Rubus niveus Thunb (Figure 6) is an upright shrub that possibly growth up to 1-2 meters. Its stems are covered with thick waxy white, especially when it was young. The leaf structure has a pinnate compound leaf type. This species has red fruits, sometimes appearing blue, green or yellow. Various of medicinal plants species that have potential as anticancer in the Cemoro Sewu hiking trail is more commonly found in the Rubus genus because it has antioxidants that can minimize the activity of cancer growth due to free radicals. The antioxidants that have potential as anticancer are flavonoids (Deighton et al., 2000). Tannins are natural phenolic compounds that protect plants against fungi and insects. Szczurek (2021). In this investigation, methanol extracts of three plant species, *Rubus niveus*, *Rubus fairholmianus*, and *Rubus ellipticus*,

(a) (b)

Figure 5. Morphology of *Rubus fraxinifolius* Poir in Lawu Mountain (a) habitus and (b) leaves and flowers

(a) (b)

Figure 6. Morphology of *Rubus niveus* Thunb in Lawu Mountain (a) habitus and (b) leaves and flowers

exhibited high cytotoxicity (Muniyandi et al., 2019; Indrayanto et al., 2020). Another portion of *Azadirachta indica* A. Juss and *Melia azedarach* Linn. including different solvents (such as ether, petroleum, methanol, hexane, and water). Both species show less anticancer activity with an IC50 value greater than 100 ɛg/mL (Malar et al., 2020; Indrayanto et al., 2020). The action method against cancer cells was not mentioned in any research. More purification is required to obtain the active ingredient in the Rubus genus methanol extract.

6. Hypericum leschenaultii Choisy

Hypericum leschenaultii Choisy (Figure 7) is an upright shrub species with a maximum growth of up to 12 meters. The stem has a reddish-brown color. The leaf structure consists of seated leaves with an ovate shape and a white bottom side. The leaves on this species' crowns are yellow. According to the research of Szegedi et al., the active compound in *Hypericum perforatum* L (St. John's Wort) isolation was stated as having the special characteristic of Napthodianthrone derivatives (Szegedi et al., 2005). The founded compound *H. perforatum* has resistance to killing cell cancer growth, especially glioma cells.

7. Bryonia sp.

Bryonia sp. (Figure 8) is a type of herbaceous vine with stems up to 3-5 m long covered by soft hairs, and its diameter ranges from 1.2-3.2 mm. When it was young, the stem was covered with fine hairs, but when it was old, it was not anymore. They also have Spiralling tendrils

(a) (b)

Figure 7. Morphology of *Hypericum leschenaultii* Choisy in Lawu Mountain (a) habitus and (b) leaves & flowers

(a) (b)

Figure 8. Morphology of Bryonia sp. in Lawu Mountain (a) habitus and (b) leaves & flowers

which grow from the leaf axils. The leaves that grow have a heart-shaped form and greenish-white flower color. This species produced green fruit close to dark blue, but there were changes into black when it ripped. The bitter taste when the fruit was eaten. Based on research conducted by Bernarba et al. and Bachir et al. *Bryonia dioica* extract could suppress the growth of cancer cells. First, the extract could apoptotic Burkitt's lymphoma BL41 cancer cells and induce G2/M cell cycle arrest in MDA-MB 231 Breast Cancer cells (Bernad et al., 2008; Benarba et al., 2012).

8. *Plantago major* L.

Plantago major L. (Figure 9) is an upright perennial herb that ranges between 30-70 cm. This species has rosette-type leaves with varied morphology, such as round or irregularly serrated, smooth or moderately smooth. The plant has a tight flower structure with an elliptical shape, with a (4-)6-34 seed structure, and the flowers are black. *P. major* has several subspecies and varieties, but each cannot be clearly distinguished, considering the presence of intermediate forms (Simmonds et al., 2002). Based on previous research, *Plantago* spp. contains efficacy to suppress the growth of cancer cells. The cancer cells that could suppress their growth are breast adenocarcinoma (MCF-7) and melanoma cell (UACC-62) (Gálvez et al., 2003), MCF-7, MDA-MB-231, HeLaS3, A549, and KB cancer cell lines MCF-7, MDA-MB-231, HeLaS3, A549, and KB cancer cell lines (Kartini et al., 2017).

At an altitude of 3,161 m asl (above station VI), the species *Digitalis purpurea* L. was found in a very small population and was only found at this altitude. Each plant species requires suitable environmental conditions to live, so the living requirements of each species are different. There was a tolerance zone where forced seed breakage occurs naturally in an inappropriate environment; this occurs in a limited number of species and they cannot grow appropriately in those conditions (Steenis & Friedberg, 2018).

9. *Digitalis purpurea* L.

Digitalis purpurea L (Figure 10) was an upright herbaceous species, its height ranging from 30-50 cm. The soft steam with yellowish green dominated their steam. This species has a single leaf arrangement with a green color and both sides are hairy. *D. purpurea* L produces the cluster arrangements flower, has five petals, and the crown is purplish white. The fruit has a conical shape with fine hairs on the skin surface with a yellow color. Finally, the seeds have a flat round shape and are yellow when young and brown when they are old. Considering the Lazaro research, the *D. purpurea* contained the compound with suppressed and apoptosis-induced characteristics for the cancer cell (López-Lázaro, 2007). According to Fujino et al. (2015), cardenolide glycosides from *Digitalis purpurea* L. have selective cytotoxicity against renal adenocarcinoma and hepatocellular carcinoma cells, making them prospective anticancer therapeutic candidates (Fujino et

(a) (b)

Figure 9. Morphology of *Plantago major* L. in Lawu Mountain (a) habitus and (b) leaves & flowers

(a) (b)

Figure 10. Morphology of *Digitalis purpurea* L. in Lawu Mountain (a) habitus and (b) leaves and flowers

al., 2015). *D. purpurea* was found outside the designated station, precisely at an altitude of 3,161 m asl. The community widely uses this plant as a medicinal plant, and it has the potential to be an anticancer. This species is only found at that altitude with a very small population.

B. Distribution and Abundance of Medicinal Plants Potentially Anticancer

The distribution and abundance of potentially anticancer medicinal plants along the Cemoro Sewu trail depended on environmental factors. The founded species with the location are displayed in Table 6..

The distribution pattern of anti-cancer plants is analyzed based on the frequency of presence and distribution patterns calculated using Eq 1 (Morishta Indeks). The processed data obtained from observations are shown in Table 7 with the number of individual plants counts per land area (Ha)..

At an altitude of 2,000 m asl (station I), only *R. chrysophyllus* species were found, which is 1 of 8 medicinal plant species with potential as anticancer. Medicinal plant species with anticancer potential at this station are indeed few because the station I is an area with quite a dense tree shade. The average light intensity measurement at the station I only shows 10.95 x 100 lux and is the lowest of the other observation stations. This causes sunlight not to penetrate the forest canopy to the forest floor, making it impossible for shrubs and bushes to develop in the shade of tree canopies, except

Table 6. Species of anti-cancer plants based on the station where they were found

No	Species	The Altitude (m asl)					
		2,000	2,200	2,400	2,600	2,800	3,000
1.	*Debregeasia longifolia* (Burm. f.) Wedd.	-	√	-	-	-	-
2.	*Rubus chrysophyllus* Miq.	√	√	-	-	-	-
3.	*Rubus lineatus* Bl.	-	√	√	√	√	√
4.	*Rubus fraxinifolius* Poir.	-	√	-	-	-	-
5.	*Rubus niveus* Thunb.	-	√	-	√	-	-
6.	*Hypericum leschenaultii* Choisy	-	-	-	√	√	√
7.	*Bryonia* sp.	-	√	-	-	-	-
8.	*Plantago major* L.	-	-	-	√	√	√

Table 7. Abundance, frequency, Morishita distribution index (Id) and distribution pattern of anticancer medicinal plants along the hiking trail.

No	Nama Spesies	Abundance (Individu per hectare)	Frequency (%)	Morishta index (Id)	Distribution pattern
1.	*Debregeasia longifolia* (Burm. f.) Wedd.	180	0.04	2.18	clumped
2.	*Rubus chrysophyllus* Miq.	470	0.21	0.87	regular
3.	*Rubus lineatus* Bl.	4,580	0.79	0.09	regular
4.	*Rubus fraxinifolius* Poir.	1,320	0.13	0.30	regular
5.	*Rubus niveus* Thunb.	250	0.13	1.64	clumped
6.	*Hypericum leschenaultii* Choisy	2,070	0.42	0.19	regular
7.	*Bryonia* sp.	5,000	0.08	2.00	clumped
8.	*Plantago major* L.	50,830	0.42	0.20	regular

for plant species that do live in the shade. (Arief, 1994). When cultivated in intricate and changing lighting conditions, plants actively fight with one another for the few available light sources. Chlorophylls and other pigments of the photosynthetic machinery absorb light once it reaches plant leaves and use it for photosynthesis (Xu, 2021). At an altitude of 2,200 m asl (station II), medicinal plant species with anticancer potential were found, namely *D. longifolia*, *R. chrysophyllus*, *R. lineatus*, *R. fraxinifolius*, *R. niveus*, and *Bryonia* sp. Station II has the highest number of medicinal plant species with anticancer potential and is the only station where all species of the genus Rubus can be found. However, not all Rubus species can grow optimally at station II. Environmental conditions at station II are the most optimal environment for the growth of *D. longifolia*, *R. fraxinifolius*, and *Bryonia* sp. species because the three species are only found in abundance at this station. The life of plant species in mountainous areas cannot be separated from the influence of abiotic components that make up the ecosystem. The ability of organisms to live in certain environmental conditions is called the tolerance range. Each species in the ecosystem has a tolerance limit so that other species found have their optimal environmental conditions for growth. At an altitude of 2,400 m asl (station III), only one medicinal plant species was found, namely *R. lineatus*. The richness of medicinal plant species that have the potential anticancer at this station is also small because station III has rocky soil conditions. Monk et al. (2000) stated that the distribution of plant species according to altitude is related to changes in soil type. Important changes in soil due to changes in altitude will affect the decrease in pH, increase in organic carbon, and decrease in rooting depth so that only certain plant species can adapt. *Digitalis purpurea* L. is widely used by the community as a medicine and has potential as an anticancer; besides, the location of the growth of this species is not far from the designated observation station. At an altitude of 3,161 m asl (above station VI) can be found *D. purpurea* species in a very small population and only located at this altitude. Each plant species requires appropriate environmental conditions to live, so the life requirements of each species are different, where they only occupy parts suitable for their lives (Djufri, 2002).

Figure 11 shows that *D. longifolia* was distributed in station II with an abundance of 1,100 individuals per hectare. The species of Rubus genus members are distributed

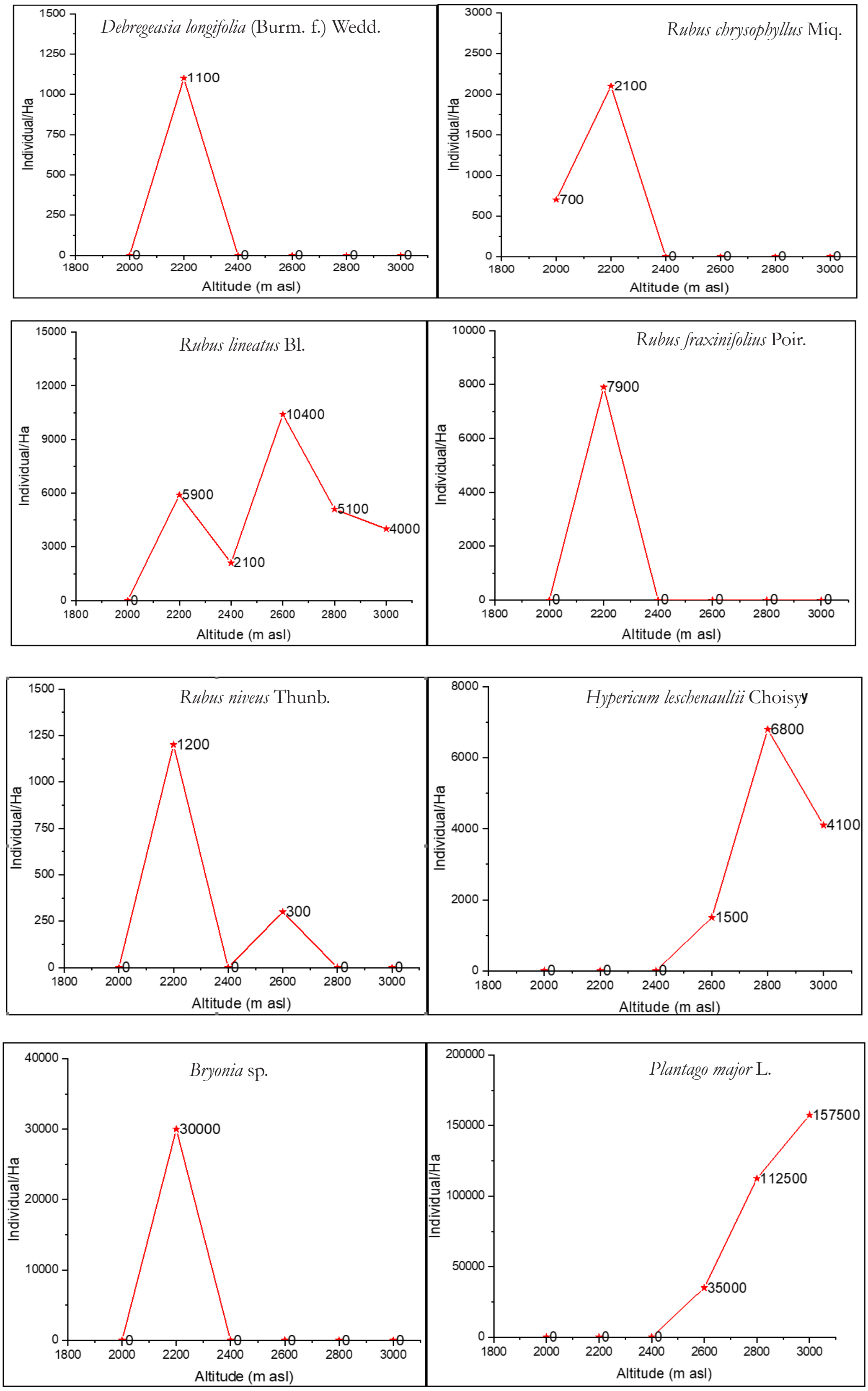


Figure 11. Graph of the abundance of each medicinal plant species potentially as anticancer in the Cemoro Sewu hiking trail observation station

and have different abundance values at each observed location. However, *R. lineatus* was the most widely distributed Rubus species along the stations. The highest abundance of *R. lineatus* was found at station IV where 10,400 individuals were found per hectare. According to station II, the species *R. chrysophyllus*, *R. fraxinifolius*, and *R. niveus* were found to have the highest abundance. In addition to Rubus species, there are also *Bryonia* sp. species with the highest abundance at station II, valued at 30,000 individuals per hectare. The adaptability of each species remained different, and it became possible that the species found along the trail were also different. Furthermore, the species with low-altitude habits are difficult to find in higher places. Additionally, station V was dominated by the *H. leschenaultii*, which was considered 6,800 individuals per hectare. The *P. major* species had the highest abundance value of 157,500 individuals per hectare compared to others in the observed station.

This exploration of the anticancer potential of plants in the Cemoro Sewu hiking trail is a finding with promising implications for discovering new cancer therapeutic agents from different altitudes. Plant growth's geographical location differences produce different secondary metabolite compound content (Rohmani et al., 2024). Although there have been several studies related to these plants, comprehensive studies that include phytochemical analysis, pharmacological studies, investigation of the mechanism of action, ecological assessment, and exploration of traditional uses can also be future research to validate the anticancer potential. It is essential to conserve Mount Lawu's biodiversity and ensure these natural resources' sustainable availability for future scientific exploration and potential therapeutic applications.

IV. CONCLUSION

Medicinal plants that potentially served as anticancer in the Cemoro Sewu hiking trail were found in six stations of eight species, such as *Debregeasia longifolia* (Burm. f.) Wedd., *Rubus chrysophyllus* Miq., *Rubus lineatus* Bl., *Rubus fraxinifolius* Poir., *Rubus niveus* Thunb., *Hypericum leschenaultii* Choisy, *Bryonia* sp., and *Plantago major* L., respectively. Medicinal plants that potentially served as anticancer in the Cemoro Sewu hiking trail, which is categorized as shrubs with specifically regular distribution patterns are *R. chrysophyllus*, *R. lineatus*, *R. fraxinifolius*, and *H. leschenaultii.* In contrast, the clumped distribution patterns are *D. longifolia* and *R. niveus*. On the other hand, the herbaceous category with a regular distribution pattern is *P. major*, while with a clumped distribution pattern is *Bryonia* sp. Medicinal plants that potentially served as anticancer in the Cemoro Sewu hiking trail have abundance values between 180-4,580 individuals per hectare for the shrub category and 5,000-50,830 individuals per hectare for the herb category, depending on the environmental conditions surrounding the hiking trails.

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CROSS-AMPLIFICATION OF *AQUILARIA CRASSNA* MICROSATELLITE DNA MARKERS IN TWO OTHER CLOSELY RELATED AGARWOOD SPECIES (*A. MALACCENSIS* AND *A. MICROCARPA*)

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CROSS-AMPLIFICATION OF *AQUILARIA CRASSNA* MICROSATELLITE DNA MARKERS IN TWO OTHER CLOSELY RELATED AGARWOOD SPECIES (*A. MALACCENSIS* AND *A. MICROCARPA*). Agarwood is a distinctive wood resin product extracted from the important genus of *Aquilaria*, but the population of agarwood-producing trees from natural forests in Indonesia is threatened due to over-exploitation, leading to an urgent call for conservation and sustainable uses. Molecular techniques such as DNA profiling have been used to ensure the legality, conservation, and sustainability of species from this genus. In this study, cross-species amplification of microsatellite markers initially developed for *Aquilaria crassna* was developed on two other closely related agarwood species (*Aquilaria malaccensis* and *A. microcarpa*), and their genetic variation was evaluated. The four loci (6pa18, 10pa17, 16pa17, and 71pa17) were used to amplify leaf genomic DNA from 55 trees across three *Aquilaria* species. The results showed that the four loci could successfully be amplified in *A. malaccensis*, *A. microcarpa*, and *A. crassna*. In addition, *A. crassna* exhibited higher genetic variation (N_a=2.75, N_e=2.35, H_e= 0.5672, and F=-0.727) than *A. malaccensis* (N_a=2.75, N_e=2.19, H_e=0.5424, and F=-0.598) and *A. microcarpa* (N_a=2.50, N_e=2.11, H_e= 0.5234, and F=-0.734) indicated the transferability of microsatellite markers in closely related agarwood species, possibly due to the flanking region in these four microsatellite regions being well-conserved in several agarwood species. These findings indicated that the markers tested here can be considered an effective tool for future studies in population and conservation genetics to support the management of agarwood genetic resources and track its supply chain to prevent overexploitation.

Keywords: Agarwood, *Aquilaria*, cross-amplification, microsatellite

AMPLIFIKASI SILANG PENANDA DNA MIKROSATELIT AQUILARIA CRASSNA *PADA DUA SPESIES KERABAT GAHARU LAINNYA (*A. MALACCENSIS *DAN* A. MICROCARPA*). Gaharu merupakan produk resin kayu yang khas yang diekstraksi dari genus penting* Aquilaria*, tetapi populasi pohon penghasil gaharu dari hutan alam Indonesia terancam punah karena eksploitasi berlebihan yang memerlukan upaya konservasi dan pemanfaatan berkelanjutan. Teknik molekuler seperti pembuatan profil DNA telah digunakan untuk memastikan legalitas, konservasi, dan keberlanjutan spesies dari genus ini. Dalam penelitian ini, amplifikasi lintas spesies penanda DNA mikrosatelit yang awalnya dikembangkan untuk* Aquilaria crassna*, dikembangkan pada dua spesies gaharu lain yang berkerabat dekat (*Aquilaria malaccensis *dan* A. microcarpa*) dan keragaman genetika mereka dievaluasi. Empat lokus (6pa18, 10pa17, 16pa17, dan 71pa17) digunakan untuk mengamplifikasi genomik DNA daun dari 55 pohon pada tiga spesies* Aquilaria*. Hasil penelitian menunjukkan bahwa keempat lokus tersebut berhasil diamplifikasi pada* A. malaccensis*,* A. microcarpa*, dan* A. crassna*. Selain itu,* A. crassna *menunjukkan variasi genetik yang lebih tinggi*

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(N_a=2.75, Ne=2.35, H_e= 0.5672, dan F=-0.727) dibandingkan A. malaccensis *(N_a=2.75, N_e=2.19, H_e= 0.5424, dan F=-0.598) dan* A. microcarpa *(N_a=2.50, N_e=2.11, H_e= 0.5234, dan F=-0.734) yang mengindikasikan adanya perpindahan penanda mikrosatelit pada spesies gaharu yang berkerabat dekat, kemungkinan karena flanking region pada keempat daerah mikrosatelit tersebut terpelihara dengan baik pada beberapa spesies gaharu. Temuan ini menunjukkan bahwa rangkaian penanda yang diuji di sini dapat dianggap sebagai alat yang efektif untuk studi genetika populasi dan konservasi di masa mendatang guna mendukung pengelolaan sumber daya gaharu dan pelacakan rantai pasokannya untuk mencegah eksploitasi berlebihan.*

Kata kunci: Amplifikasi silang, Aquilaria*, gaharu, microsatellite*

I. INTRODUCTION

Agarwood resin (gaharu) from Indonesia, which is harvested from the trunk or branches of *Aquilaria* and *Gyrinops* species (Thymelaeaceae), is known to be used for the highly valued incense production (Pern et al., 2020; Putri et al., 2017; Siburian et al., 2019). Due to overexploitation driven by increasing market demand, the natural population of agarwood is threatened with extinction (Destri et al., 2020; Lian et al., 2016; Singh et al., 2015; Soehartono & Newton, 2000). Therefore, sustainable harvesting of agarwood from the natural populations is controlled through production quotas, as listed in Appendix II of the Convention on International Trade in Endangered Species (CITES) (CITES, 2024; Ministry of Environment and Forestry & National Research and Innovation Agency, 2024).

Despite the vital role of natural populations in supplying agarwood, efforts to increase agarwood production through plantations are implemented in various ways. Therefore, several agarwood plantations have been established since the 1980s, including in Indonesia (Abdulah et al., 2022; Eurlings et al., 2010). In particular, small-scale plantations have been established sporadically, where the species grown are predominantly *Aquilaria malaccensis* and *A. microcarpa*. However, the establishment of plantations and seedling translocations raises concerns about maintaining the genetic integrity of wild populations. Significant genetic differentiation among wild *Aquilaria malaccensis* populations was observed (Rachmat et al., 2024), highlighting their evolutionary and geographical isolation and emphasizing the need to regulate seedling translocations across regions. Without such regulation, mixing genetic material between plantation and wild sources may threaten natural populations and complicate agarwood product traceability. As a consequence, current agarwood products in the market may consist of mixed wood from plantations and natural sources, where discrimination of agarwood from these two sources is still difficult to resolve (Eurlings et al., 2010; Li et al., 2016; Wu et al., 2020). Therefore, investigating agarwood genetic variation patterns in both plantations and natural populations is necessary to provide helpful information, particularly on the origin of agarwood. This can be enhanced through the use of molecular marker techniques, which have significantly advanced the study of forest tree species over the past decade (Nurtjahjaningsih et al., 2020; Spooner et al., 2005; Wang & Szmidt, 2001). With the latest developments in molecular biology, researchers now have many options for conducting such studies.

Highly polymorphic microsatellites are excellent DNA markers suitable for studies investigating genetic variation, ranging from the population level to the individual level (Lee et al., 2004; Mottura et al., 2005; Wang et al., 2018). Microsatellites, also referred to as simple sequence repeats (SSRs), serve as valuable molecular markers utilized in population genetic studies of tree species, particularly those found in tropical forests (Dwiyanti et al., 2014a; Dwiyanti et al., 2015; Lee et al., 2004; Mottura et al., 2005; Ouinsavi et al., 2006). However, developing these markers can be both costly and time-consuming. Utilizing microsatellites from related species can help reduce these costs, ultimately saving both time and money (Barbará et al., 2007; López-Vinyallonga, 2011). This approach would also encourage further studies to adopt similar methods. Microsatellites have been identified in various organisms and are generally dispersed throughout their genomes (Deng et al., 2016; Hancock, 1999; Koubínová & Grant, 2024; Xiong et al., 2012).

The pioneering development of microsatellite markers in the genus *Aquilaria* represents a significant advancement in the creation of a DNA fingerprint database for *Aquilaria crassna*. This database is essential for accurately tracing the geographic origins of traded wood and incense samples, with critical forensic applications in Thailand and Vietnam (Eurlings et al., 2010). This study tested for cross-species amplification in *Aquilaria sinensis* and *A. rugosa* found in Vietnam and China (Eurlings et al., 2010). Following this, a second set of markers was developed for *A. malaccensis* from Malaysia (Tnah et al., 2012) and *A. malaccensis* from India (Singh et al., 2015). The last set was developed for *A. sinensis*, which occurred in China, and these markers were tested for cross-species amplification in *A. yunnanensis* and *A. crassna*, which also occurred in China (Wang et al., 2018). These three sets of markers were further tested for cross-species amplification in ten other *Aquilaria* species in Malaysia, including *A. beccariana*, *A. hirta*, *A. microcarpa*, *A. rostrata*, *A. rugosa*, *A. subintegra*, and *A. yunnanensis* (Pern et al., 2020). The study revealed 13 cross-amplifiable markers, of which only one was polymorphic across all species. Given the findings of previous studies, it is crucial to test the cross-species amplification of microsatellite markers developed for *Aquilaria* species on other *Aquilaria* species in Indonesia. This is particularly important due to the potential genetic uniqueness of the Indonesian population compared to those in Malaysia, Vietnam, Thailand, India, and China. Additionally, there is a notable lack of reports on studies regarding the cross-species amplification of microsatellite markers in *Aquilaria* species within Indonesia. As a preliminary study step, the present study evaluated the cross-species amplification of microsatellite markers originally developed for *A. crassna* on two native and endangered *Aquilaria* species in Indonesia: *A. malaccensis* and *A. microcarpa* (Nurtjahjaningsih et al., 2020; Qiptiyah et al., 2021). Furthermore, this study aimed to investigate the effectiveness of these *Aquilaria crassna* microsatellite DNA markers in two closely related agarwood species, *A. malaccensis* and *A. microcarpa*, from the plantation populations in West Java, Indonesia, and to examine the genetic variation among the three studied *Aquilaria* spp. Identifying suitable microsatellite markers can enhance future genetic studies on these species, particularly in analyzing diversity and population structure. In wild populations, it can aid in developing genetic barcodes to determine the accurate identification of species names and to develop genetic fingerprints to identify the population origins. In contrast, in planted populations or products, it can be utilized to trace their genetic lineage. The findings of this study can support the Indonesian government and law enforcement agencies to take decisive action in managing agarwood resources, monitoring the supply chain to prevent overexploitation and illegal logging, and formulating strategies to conserve agarwood-producing species.

II. MATERIALS AND METHODS

A. Study Site

Leaves from a total number of 55 individual trees representing three species, i.e., *Aquilaria crassna* (n=15), *A. malaccensis* (n=32), and *A. microcarpa* (n=8), which grow in the plantation areas in West Java Province, Indonesia, and also in natural forest in Riau Province, Indonesia (population of *A. malaccensis* only) were collected for DNA analysis (Table 1). The leaf samples were then preserved in a plastic zip containing silica gel (1:5 v/v) in the field for further DNA extraction at the Laboratory of Forest Genetics and Molecular Forestry, Department of Silviculture, Faculty of Forestry and Environment of IPB University in Bogor Regency, West Java Province, Indonesia.

B. Microsatellites Analysis

DNA extraction of dried leaves from 55 trees consisting of three *Aquilaria* spp. (i.e. *Aquilaria crassna*, *A. malaccensis*, and *A. microcarpa*) (Table 1) was carried out using the CTAB (Cetyltrimethylammonium bromide) protocol with modifications (Doyle & Doyle, 1990). All four pairs of microsatellite DNA markers or simple sequence repeats (SSRs) developed for *A. crassna* (Table 2) (Eurlings et al., 2010; Siburian et al., 2019) were amplified in *A. crassna*, *A. malaccensis*, and *A. microcarpa* samples in this study. Polymerase Chain Reactions (PCR) were carried out in a final volume of 15 µl for one reaction, containing approximately 20 ng of genomic DNA (2 µl), 7.5 µl Go Taq Green Master Mix Kit (Promega), 1.5 µl forward primer, 1.5 µl reverse primer, and 2.5 µl H2O. Amplification was initially conducted by modifying the PCR protocol of Eurlings et al. (2010) to determine the optimal PCR profile for the three *Aquilaria* species studied. The thermal cycling profile used in the present study consisted of 95°C for 2 min for initial

Table 1. Sampling location of *Aquilaria crassna, A. malaccensis*, and *A. microcarpa* in Indonesia

No.	Species name	Study site	Number of sample (n)
1	*Aquilaria crassna*	Biotrop, Bogor, West Java	4
		Greg Hambali Garden, Bogor, West Java	2
		Gunung Walat University Forest, Sukabumi, West Java	9
		Total	**15**
2	*Aquilaria malaccensis*	Biotrop, Bogor, West Java	4
		Greg Hambali Garden, Bogor, West Java	2
		Bogor Botanical Garden, Bogor, West Java	4
		Gunung Walat University Forest, Sukabumi, West Java	2
		Muara Fajar, Rumbai Barat, Riau	20
		Total	**32**
3	*Aquilaria microcarpa*	Greg Hambali Garden, Bogor, West Java	2
		Gunung Walat University Forest, Sukabumi, West Java	5
		Bogor Botanical Garden, Bogor, West Java	1
		Total	**8**
		Grand Total	**55**

Table 2. Characteristics of four polymorphic nuclear microsatellites developed for *Aquilaria crassna* by Eurlings et al. (2010)

Locus	Primer sequences (5'–3')	Repeat	Size range (bp)	Number of alleles	Ta (°C)
6pa18	F: TGAGGCGTGAGTGAGATATTGATT R: CCTTCCTCTCTTCTTACCTCACCA	(CA)8	180–210	7	50
10pa17	F: ACACACTGTTATGGTCTACAGCTT R: CGCCATCTCATAATATTCTAATGTA	(CA)12	152–156	3	50
16pa17	F: AGTGAACAACTTGACTAGGCTTG R: GCTGAACACAACAAGATATCACC	(CA)19	143–155	6	59
71pa17	F: AGCAAACAGTGGGATAAGGTC R: AGAAAGGAGGCGAAACGAAT	(CA)15	152–224	15	54

Note: F = forward, R = reverse, Ta = annealing temperature.

denaturation, followed by 35 cycles of 95^{o}C for 1 min for denaturation, 49-54 oC for 2 min for annealing, 72^{o}C for 2 min for extension, and 72^{o}C for 10 min for final extension. To ensure the reliability of the results, one individual from each species was tested on four markers, and the amplification process was repeated twice, following the methodology outlined by Pern et al. (2020). Afterward, amplification testing of each marker on 55 samples was performed once. All PCR reactions were performed in the Peltier Thermal Cycler (PTC-100, MJ Research). PCR products were electrophoresed in 2% agarose gel in 1x TAE buffer and stained with ethidium bromide for visualization on a UV transilluminator. Genotyping was carried out on a 30% polyacrylamide gel. Product sizes were scored against a 100 bp DNA ladder (Vivantis).

C. Data Analysis

Successful PCR amplification was validated by the presence of a single DNA band within the expected size range of the amplification products. A DNA fragment is considered to be outside the predicted size range if it deviates by 100 bp (base pair) larger or smaller than the original sequence (Arnold et al., 2002). The sizes of DNA fragments were assessed visually by comparing them to a standard DNA molecular weight marker and scoring them accordingly. If multiple bands appeared near the expected size range, they were categorized as stuttering bands and excluded from the study. The DNA electropherogram was then analyzed to determine the putative genotype. General estimation of genetic variation of each species, including the number of alleles per locus (Na), observed heterozygosity (HO), expected heterozygosity (He), and the fixation index (F), was calculated using GenAlEx software version 6.503 (Peakall & Smouse, 2012). Furthermore, deviations from the Hardy-Weinberg equilibrium were assessed for each locus in every population using GENEPOP 4.7.5 (Raymond & Rousset, 1995; Rousset, 2008).

III. RESULTS AND DISCUSSION

A. Microsatellite Marker Amplification of *Aquilaria crassna* in *A. malaccensis* and *A. microcarpa*

In this study, four nuclear microsatellite markers developed for *A. crassna* species in Thailand, namely 6pa18, 10pa17, 16pa17, and 71pa17 (Eurlings et al., 2010), were able to successfully amplify the three Indonesian agarwood species, namely *A. crassna*, *A. malaccensis*, and *A. microcarpa*. The success of this cross-amplification was indicated by the appearance of the four microsatellite bands between 100 bp and 200 bp in each *Aquilaria* species, specifically, i.e., 143-155 bp for locus 16pa17, 152-156 bp for locus 10pa17, 152-224 bp for locus 71pa17, and 180-210 bp for locus 6pa18 (Figure 1).

Four microsatellite loci (100%) produced amplicons of the expected size. The total number of alleles for *A. malaccensis* and *A. microcarpa* species ranged from two to three, i.e., two alleles at locus 6pa18 and three alleles at loci 10pa17, 16pa17, and 71pa17 (Table 3). Four alleles (143 bp, 145 bp, 153 bp, and 186 bp) were identified in the *A. crassna* study by Eurlings et al. (2010) and were also observed in all species tested in this study. Additionally, two previously unidentified alleles were identified in the *A. crassna* study (Eurlings et al., 2010). However, they were identified in this study, i.e., allele 158 bp found in *A. microcarpa* samples and allele 164 bp in *A. malaccensis* and *A. crassna* samples (Table 4). These findings indicated that the markers are polymorphic across various agarwood species, which may demonstrate the presence of genetic variation within these species. This variation is essential for understanding evolutionary processes and population dynamics.

In contrast to this study, which demonstrated the success of all four markers on three Indonesian *Aquilaria* species, a previous study by Pern et al. (2020) found that locus 10pa17 was ineffective in amplifying samples from *A. malaccensis* and *A. microcarpa* collected in

Malaysia. The locus 10pa17 also failed to amplify other Malaysian *Aquilaria* species, including *A. beccariana, A. hirta*, *A. rugosa*, and *A. yunnanensis* (Pern et al., 2020), as indicated by multiple bands resulting from non-specific amplification.

The success of amplification in the present study may be attributed to the suitability, efficiency, and optimization of the PCR process. Unspecific primers can amplify other regions in the genome that are not targeted or even absent in the amplified regions. PCR

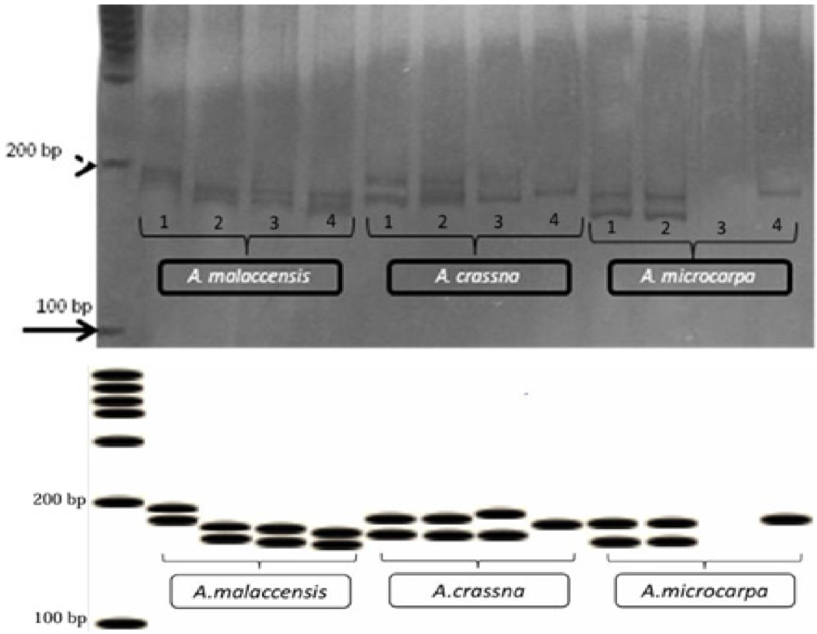

Figure 1. Polyacrylamide gel electrophoresis bands representing four microsatellite markers used in this study on *A. malaccensis*, *A. crassna*, and *A. microcarpa* species. Locus 6pa18 (1), locus 10pa17 (2), locus 16pa17 (3), and locus 71pa17 (4).

Table 3. Results of microsatellite marker amplification of *Aquilaria crassna* in *A. malaccensis* and *A. microcarpa*

Locus	**Polymorphism and detected number of alleles**	
	Aquilaria microcarpa	***Aquilaria malaccensis***
6pa18	++ (2)	++ (2)
10pa17	+++(3)	+++(3)
16pa17	+++(3)	+++(3)
71pa17	+++(3)	+++(3)

Note: (++) = polymorphic locus with two alleles; (+++) = polymorphic locus with three alleles

Table 4. Allelic variation in four microsatellite markers in three *Aquilaria* species

No.	**Species**	**Allele (bp)**																
		143	**145**	**147**	**151**	**152**	**153**	**154**	**158**	**164**	**180**	**186**	**194**	**196**	**206**	**210**	**216**	**224**
1	*Aquilaria malaccensis*	✓	✓	✓	-	✓	✓	✓	-	ϕ	-	✓	-	✓	-	-	-	-
2	*Aqularia microcarpa*	✓	✓	✓	-	✓	✓	✓	ϕ	-	-	✓	-	-	-	✓	-	-
3	*Aquilaria crassna*	✓	✓	-	-	-	✓	-	-	ϕ	✓	✓	-	✓	-	-	✓	✓

Note: ✓= The allele was identified in the *A. crassna* study (Eurlings et al., 2009) and also in this current study; - = This allele was detected in a study of *A.crassna* (Eurlings et al., 2009) but was not detected in the current study; Φ= This allele was not detected in the *A.crassna* study (Eurlings et al., 2009) but was detected in the current study. Alleles 155-156, 168-178, and 198-202 were detected in a study of *A.crassna* (Eurlings et al., 2009) but were not detected in the current study.

optimization is also needed to produce the desired yield. This optimization pertains to the temperature of DNA denaturation and annealing during the PCR process. If the denaturation temperature is set too low or the denaturation time is insufficient, it can lead to imperfect denaturation processes, such as the failure to separate double-stranded DNA into single-stranded DNA, and prevent new DNA polymerization from occurring. While too high a denaturation temperature or too long a denaturation time may cause the DNA template to be degraded, or may generate no identifiable product (Gustafson et al., 1993; Takara Bio, 2024). In addition, selecting an annealing temperature that is too high can prevent any amplification products from forming, while a temperature that is too low may unintentionally amplify non-specific DNA fragments. This unwanted amplification can create the appearance of multiple bands on the agarose gel, which distracts from the intended results and complicates data interpretation (Borah, 2011; Rychlik et al., 1990; Yunita et al., 2023).

B. Genetic Variation of Three *Aquilaria* spp.

Four microsatellite markers that were successfully amplified were then evaluated for their ability to determine the genetic variation of the three agarwood species. The results showed that genetic variation of *A. crassna* had a slightly higher genetic variation (N_a=2.75, N_e=2.35, and H_e= 0.5672) than *A. malaccensis* (N_a=2.75, N_e=2.19, and H_e= 0.5424) and *A. microcarpa* (N_a=2.50, N_e=2.11, and H_e= 0.5234) (Table 5). The fixation index (F) value was notably negative, indicating an excess of heterozygotes in all species (Dwiyanti et al., 2014b). However, this value was not significantly different from zero in *A. microcarpa* (Table 5). This result pattern indicated the transferability of microsatellite markers in closely related agarwood species, possibly due to the flanking region in these four microsatellite regions being well-conserved in several agarwood species (Dwiyanti et al., 2014a; Ng et al., 2004).

The genetic variation indicated by the expected heterozygosity of *A. crassna* in the present study (H_e = 0.5672) is slightly higher than that of *A. crassna* (H_e = 0.542) studied by Wang et al. (2018), which used *A. sinensis* to amplify *A. crassna* samples. This pattern suggested that a species' genetic variation is likely high when using markers specifically developed for that species. However, this variation may slightly decrease when using markers that are not specifically tailored to that species.

Genetic variation is essential for maintaining the long-term stability of the forest ecosystem, as it influences the ability of tree species to adapt to changing environmental conditions. The amount and distribution of genetic variation are shaped by genetic systems and evolutionary factors. Understanding genetic variability is crucial for developing effective conservation and breeding strategies (Rohlf, 1998). Specifically, knowledge about the genetics of agarwood species can aid in designing effective tree breeding programs, conservation strategies for genetic resources, and establishing a DNA fingerprint database. This database would help identify the geographic and plantation origins of traded agarwood (Eurlings et al., 2010).

Table 5. Genetic variation of three Indonesian *Aquilaria* species using four microsatellite markers

No	Agarwood species	N	N_a	N_e	H_o	H_e	F
1	*Aquilaria crassna*	15	2.75	2.35	0.967	0.5672	-0.727***
2	*Aquilaria malaccensis*	32	2.75	2.19	0.867	0.5424	-0.598***
3	*Aquilaria microcarpa*	8	2.50	2.11	0.906	0.5234	-0.734^{ns}

Note: N= sample size; N_a= number of alleles; N_e= effective number of alleles; H_o = observed heterozygosity; H_e= expected heterozygosity; F = Fixation Index with the significance level for deviation from the Hardy-Weinberg Equilibrium (HWE): P < 0.001 (***), not significant (ns).

The present study revealed that four microsatellite markers evaluated in this study could be used as molecular tools for further population genetics studies, provenance identification, and genetic resource management and conservation of *Aquilaria* species in Indonesia. Practical application for discriminating between artificial and natural populations might also be another helpful option. In addition, the loci characterized here can also be used for genotyping of clones of agarwood produced by commercial tissue culture techniques within the context of seedling quality control.

Additional genetic aspects of reproductive systems in agarwood can also be explored to assess genetic variability loss, inbreeding depression, gene flow, the influence of selection, mating systems, and the identification of suitable germplasm for conservation efforts. The genetic variation data gathered in this present study can serve as valuable references for future population and conservation genetics studies. Considering the genetic variation in the three studied planted agarwood species in West Java, the breeding program may be started using the available plantation materials as base populations. However, a future backup of genetic resources from other populations, preferably from natural ones, is recommended and should be well-planned in the long-term breeding program.

IV. CONCLUSION

Four microsatellite markers originally developed for *Aquilaria crassna* in Thailand (6pa18, 10pa17, 16pa17, and 71pa17) were successfully amplified in three Indonesian *Aquilaria* species (*A. crassna*, *A. malaccensis*, and *A. microcarpa*). The success of amplification indicated the transferability of microsatellite markers, possibly due to the suitability of the markers and the efficiency and optimization of PCR processes. Moreover, the genetic diversity of the three *Aquilaria* species using the four markers also showed comparable values with slightly higher values in *A. crassna*, suggesting that the four markers are reliable enough to be used in future studies related to the genetic resources of these three *Aquilaria* species, such as population genetics, breeding, and conservation programs. This approach will support the management of *Aquilaria* resources and help track its supply chain to prevent overexploitation and illegal logging. While this study employs DNA band assessment methods on acrylamide gels, it is important to note that this approach has limitations, particularly when distinguishing smaller polymorphic bands that differ by just 2–3 base pairs due to the short length of the gels. Nevertheless, the study successfully demonstrates the presence of polymorphic sites in the three species of agarwood. To enhance the accuracy of future genetic population studies, it is recommended that a Sanger Sequencing instrument be utilized to determine SSR fragment sizes precisely. This advancement will contribute to the ongoing efforts to protect and manage valuable *Aquilaria* resources effectively.

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INDOLE BUTIRAT ACID (IBA) INDUCES HIGH FREQUENCY MULTIPLICATION IN ENDANGERED TITAN ARUM (*Amorphophallus titanum* (Becc.)): AN APPROACH TO GERMPLASM CONSERVATION

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INDOLE BUTIRAT ACID (IBA) INDUCES HIGH FREQUENCY MULTIPLICATION IN ENDANGERED TITAN ARUM (*Amorphophallus titanum* (Becc.)): APPROACH TO GERMPLASM CONSERVATION. Titan arum (*Amorphophallus titanum* (Becc.)) was an endemic flora found only on the island of Sumatra, listed as endangered and possessing the largest flower among 170 species of *Amorphophallus*. Conservation activities could benefit from the use of plant propagation through cuttings. The success of cuttings was determined by the concentration of plant growth regulators (PGR) to induce the formation of roots, corms, and shoots, making the study of PGR concentration important. This study aimed to find the best IBA concentration to induce roots, corms, and shoots in *A. titanum*. The research was conducted from February to October 2023. The study was designed based on a completely randomized design with treatments of IBA concentration consisting of 5 levels: 0, 5, 10, 15, and 20 mg L-1. The results showed that an IBA concentration of 15 mg L-1 produced the best survival percentage (100%), rooting percentage (93.33%), corm formation percentage (93.33%), shoot formation percentage (76.67%), and an average of 1.20 shoots per cutting on *A. titanum* petiole cuttings.

Keywords: Biodiversity, conservation, endemic, extinct, plant growth regulator

*INDOLE BUTIRAT ACID (IBA) MENDORONG LAJU MULTIPLIKASI YANG TINGGI PADA BUNGA BANGKAI (*Amorphophallus titanum *(Becc.)): PENDEKATAN UNTUK KONSERVASI PLASMA NUTFAH. Bunga bangkai (*Amorphophallus titanum *(Becc.)) adalah flora endemik yang hanya ditemukan di pulau Sumatera. Tumbuhan ini terdaftar sebagai terancam punah dan memiliki bunga terbesar di antara 170 spesies *Amorphophallus*. Perbanyakan tanaman melalui stek dapat digunakan untuk mendukung kegiatan konservasi. Keberhasilan stek ditentukan oleh konsentrasi zat pengatur tumbuh (ZPT) untuk merangsang pembentukan akar, umbi, dan tunas, sehingga studi mengenai konsentrasi ZPT menjadi penting. Penelitian ini bertujuan untuk mendapatkan konsentrasi IBA terbaik untuk merangsang pembentukan akar, corm, dan tunas pada *A. titanum*. Penelitian ini dilakukan dari bulan Februari hingga Oktober 2023. Penelitian dirancang berdasarkan rancangan acak lengkap dengan perlakuan konsentrasi IBA yang terdiri dari 5 taraf: 0, 5, 10, 15, dan 20 mg L-1. Hasil penelitian menunjukkan bahwa konsentrasi IBA sebesar 15 mg L-1 menghasilkan persentase hidup terbaik (100%), persentase berakar (93,33%), persentase pembentukan corm (93,33%), persentase bertunas (76,67%), dan rata-rata jumlah tunas sebanyak 1.2 tunas pada stek petiole *A. titanum*.*

Kata kunci: Biodiversitas, endemic, konservasi, punah, zat pengatur tumbuh

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I. INTRODUCTION

A recent report indicated that Indonesia ranked 8th in plant diversity with 19.232 species (World Rain Forest, 2023). One of Indonesia's endemic flora, the Titan arum (*Amorphophallus titanum* (Becc.)), was found only on the Sumatra islands and listed as endangered. *A. titanum* also possessed the largest flower among 170 species of *Amorphophallus* and other flowering plants worldwide (IUCN Redlist, 2024). The flower height ranged from 179.7 cm (Latifah et al., 2015) to 274 cm (Lobin et al., 2007). Despite its great potential, the uses of *A. titanum* are still largely unexplored, unlike species such as *Amorphophallus konjac*, *Amorphophallus muelleri*, and *Amorphophallus paeoniifolius*. For instance, people have used the tuber's glucomannan content to produce food and medicine (Tester & Al Shazzewi, 2016; Choi et al., 2020).

The Government Regulation Number 7 of 1999 and the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.92/MENLHK/SETJEN/KUM.1/8/2018 (KLHK, 2018) both protect *A. titanum*. Various factors such as habitat destruction or deforestation, mistaken tuber exploitation for porang (*A. muelleri*), long reproductive times, and pollination failure due to the protogynous nature of the flower caused the population decline (Korotkova & Barthlott, 2009; Sudarmono et al., 2016; Yudaputa et al., 2021).

In-situ and ex-situ conservation programs are crucial to preserving *A. titanum*. Researchers have conducted several studies to develop propagation methods, such as seed germination (Latifah & Purwantoro, 2015), shoot induction from peculiar callus (Yuzammi et al., 2018), and in vitro culture (Irawati et al., 2017). However, these propagation methods had their drawbacks; propagation using seeds heavily depended on the success of natural cross-pollination, shoot induction from peculiar callus was only effective on mature petiole cuttings, and in vitro culture required standardized procedures to regenerate callus into plantlets.

Therefore, vegetative propagation using petiole cuttings has become a viable and quick solution for *A. titanum*'s conservation efforts. The advantage of using cuttings was that the parent plant would remain alive, and its tuber would produce new shoots. However, the success of cuttings was highly dependent on the emergence of roots at the cut site. Several studies on using plant growth regulators (PGR) on cuttings have been conducted on various Amorphophallus genera. According to Aryadi (2004), the use of Rootone F, which contained auxin, was only successful in *A. paeoniifolius* and *A. muelleri* but not in *A. titanum*. Cahyaningsih and Siregar (2013) reported that soaking rachis cuttings of *A. paeoniifolius* in 1 mg L^{-1}6-*Benzyl Amino Purine* (BAP) and 1 mg L^{-1}*naphthalene Acetic Acid* (NAA) did not give optimal results. Furthermore, Yuzammi and Handayani (2019) also reported that 20 mg L^{-1} NAA induced roots on rachis cuttings of A. paeoniifolius.

One of the plant growth regulators frequently used to stimulate root growth is *Indole Butyric Acid* (IBA). Studies have reported that IBA is the most effective hormone for plant propagation through cuttings, as it has better stability and consistently stimulates root induction and formation in various plant species compared to *Indole Acetic Acid* (IAA) and NAA. In *Solanum procumbens*, using IBA is more effective than NAA and IBA (Tien et al., 2021). Prasad et al. (2022) stated that IBA is more effective in inducing rooting than IAA in *Nerium oleander* plants. The same effect is observed in *Chrysanthemum indicum* cuttings (Ghimire et al., 2022).

Various research has demonstrated the successful use of IBA at concentrations ranging from low to high on different plant species. Sabatino et al. (2013) found that 3000 mg L-1IBA produced the best rooting percentage, number of roots, root length, and shoot height in *Nerium oleander* cuttings. Ningsih et al. (2014) reported that 20 mg L^{-1} IBA produced the highest number of roots in *Nepenthes bicalcarata* Hooker cuttings, but increasing the concentration led to a decrease in the number of roots. The application of 500 mg L^{-1} IBA positively affected the rooting percentage, number of roots, and root length in blueberry (*Vaccinium* spp.) cuttings (Koyama et al., 2019). Abdel-Rahman et al. (2020) also reported that 100 mg L-1 IBA was the best treatment for root induction of *Conocarpus erectus* L. cuttings. Similarly, IBA had a better effect at the same concentration than IAA on *Morus alba* cuttings (Chen et al., 2023). Additionally, 150 mg L^{-1} IBA was the best concentration on *Rhododenderon micranthum* cutting (Oh et al., 2023). These studies show that IBA is effective in stimulating root and shoot formation, enhancing vegetative growth, and improving plant survival rates. Each plant species responds differently to IBA concentrations, making it essential to conduct proper testing to determine the optimal concentration for specific species.

Information about the optimum concentration of IBA to stimulate root, corm, and shoot formation in *A. titanum* is still limited. Recent studies have reported that 15 mg L^{-1} IBA is the best concentration to induce root and corm formation in *A. titanum*. However, this research has not successfully produced shoots or seedlings of *A. titanum*. Therefore, further studies on vegetative propagation are still needed (Setiawan et al., 2023). Underscoring the critical need for research on IBA to support future conservation efforts. The research aimed to develop a multiplication method for *A. titanum* through cutting. Multiplication is a plant propagation technique using segments of the parent plant to get a seedling. In this study, various concentrations of IBA were used to induce the growth of roots, corms, and shoots on the petiole cuttings. The use of IBA was expected to accelerate and improve the success of rooting, corm formation, and shoot development, thus supporting the conservation and preservation efforts. This method aimed not only to increase the number of *A. titanum* but also to maintain genetic diversity and ensure the survival of this species in its natural habitat and other conservation centers. The results of this research are expected to contribute significantly to the conservation efforts of the *A. titanum*.

II. MATERIAL AND METHOD

A. Study Site/Location and/or materials

The research was conducted from February to October 2023 in the greenhouse of the Faculty of Agriculture, Universitas Andalas. The tools used included pots, hand sprayers, sterile knives, measuring cups, Erlenmeyer flasks, micropipettes, plastic covers, labels, rulers, measuring tapes, threads, and a camera. The materials used consisted of *A. titanum* petiole cutting from seedlings acclimatized in the Tissue Culture Laboratory, Faculty of Agriculture, Universitas Andalas. This seedling is approximately 8 months old, characterized by healthy seedlings, fresh green leaves, a petiole height of 30-40 cm and diameter of 1-1.5 cm (Figure 1a), IBA, distilled water, rice husk charcoal and sphagnum moss (1:1 v/v) as the planting medium.

B. Methods

The research was designed as a completely randomized design (CRD) with the treatment of IBA concentrations consisting of five levels: 0, 5, 10, 15, and 20 mg L^{-1}. Each treatment level was repeated three times, resulting in a total of 15 experimental units, each consisting of 10 cuttings. Petioles were cut using a sterile knife to a length of about 15 cm with a 45-degree angled cut. The cuttings were soaked in the IBA solution for 20 minutes with a soaking depth of 2 cm.

After soaking, the cuttings were planted in a mixture of sphagnum moss and rice husk charcoal in a 1:1 ratio (v/v), then covered and incubated for 12 weeks in the greenhouse. The observed variables included the survival percentage of cuttings, corm induction percentage, rooting percentage, sprouting percentage, number of roots, root length, shoot height, number of shoots, leaf length, and leaf width. Observations for all variables were conducted in the last week of the study.

C. Analysis

The observation data were statistically analyzed using analysis of variance (ANOVA) at a significance level of less than 5%. Posthoc test was conducted using the Duncan Multiple Range Test (DMRT) if the p-value (probability) was less than 0.05. Data analysis was performed using the Statistical Tool for Agricultural Research (STAR) software.

III. RESULTS AND DISCUSSION

Survival Percentage of Cuttings, Corm Induction Percentage, and Rooting Percentage

Soaking the petioles of A. titanum in an IBA solution affected the survival percentage of cuttings, corm induction percentage, and rooting percentage. The 15 mg L^{-1} IBA treatment was the best result, providing the highest survival percentage (100%), corm induction percentage (93.33%), and rooting percentage (93.33%) compared to all other treatments (Table 1).

The surviving cuttings were characterized by green color, corm formation, root development, and firmness without rotting. In contrast, the dead cuttings were identified by a color change to yellowish-brown, softening, rotting, shriveling, cracking at the cut ends, and drying out. These results were better than those reported by Yuzammi and Handayani (2019), who found that rachis cuttings of suweg (*A. paeoniifolius*) had a survival percentage of 80.00% with the application of NAA up to 30 ppm. Corm induction begins with the swelling of the wounded part of the cutting. This swollen section forms a cluster of undifferentiated cells, known as callus, which is white. The callus then enlarges and forms a corm, which, in further processes, will develop roots (Liu et al., 2014).

Plant regeneration that begins with root induction formed from wounds or stress on the planting material is also known as De novo root regeneration (DNRR) (Steffens & Rasmussen, 2016). The morphogenesis process of petiole cuttings progresses through a critical stage in the eighth week after planting, characterized by forming a corm (Figure 1b). During this phase, the initial petiole gradually shrinks, dries out, and eventually disappears (Figure 1c), leaving a corm with a diameter of 1–2 cm (Figure 1d). This corm functions as a primary storage organ, facilitating subsequent growth stages. New shoots and roots emerge from the corm, marking the initiation of vegetative development (Figure 1e). The formation of the corm represents a pivotal stage in the vegetative propagation of *A. titanum*, as it serves as a storage organ for photosynthates and acts as the foundation for root and shoot development. Observing the percentage of corm formation is crucial, as it marks the initial stage of plant establishment. The corm is irregularly round, with a brown on the outside and white to yellowish-orange on the inside, highlighting its role in storing energy reserves necessary for regeneration and growth. Wulandari et al. (2013) reported that IBA could stimulate and assist cells in differentiating to form roots. Hardjo et al. (2023) reported that auxin can stimulate root formation in *A. muelleri*. Agustiansyah et al. (2014) also reported that increasing IBA concentration positively

Table 1. Survival percentage, corm induction percentage, and rooting percentage of cuttings at 12 weeks after planting

IBA Consentration (mg L^{-1})	Survival percentage (%)	Corm induction percentage (%)	Rooting percentage (%)
0	50.00 ±20.0 c	40.00±20.8 b	33.33± 15.3 b
5	96.67± 5.6 ab	96.67±46.2 a	93.33± 5.8 a
10	60.00± 20.8 bc	60.00± 10.0 ab	53.33± 25.2 b
15	100.00± 0.0 a	93.33± 5.6 a	93.33± 11.5 a
20	60.00± 36.0 bc	60.00±20.0 ab	53.33± 32.1 b

Note: Numbers followed by the same lowercase letters in different columns are not significantly different based on the 5% DMRT test.

correlates with the percentage of root formation in rose apple (*Syzygium malaccense* (L.) Merr & Perry).

Several studies have reported that the expression of endogenous hormones and nutrient allocation in cuttings are influenced by exogenous auxin. Chen et al. (2023) found that the application of exogenous auxin (ABT-1) can increase endogenous IAA levels and affect the formation of adventitious roots. Besides cell division, cell elongation also occurs when endogenous IBA levels increase (Shang et al., 2021). Furthermore, it is known that auxin can influence endogenous ABA levels, a growth-inhibiting hormone. ABA levels increase during the preparation of root primordia formation and then decrease during the differentiation process of root primordia and root formation (Liu et al., 2021).

Roots not only function in water and nutrient absorption but also support the plant's structure, store photosynthates, and synthesize cytokinin hormones, which play a role in cell division and differentiation, vascular tissue development, and root morphogenesis (Papon & Caurdavault, 2022). Cytokinin is known to stimulate the Cytokinin response regulator (RRs) genes, which are key transcription factors playing a crucial role in root morphogenesis. More than 25 RR proteins are responsible for this process (Zhang et al., 2022).

Root Length and Number of Roots

Observations of root length and the number of roots were conducted at the end of the study. The use of IBA affected the number of roots but not the root length. The root length of *A. titanum* across all IBA concentrations ranged from 5.33 cm to 8.03 cm. The best treatment was the 10 mg L^{-1} IBA concentration, resulting in the highest number of roots, averaging 9.27 per cutting (Table 2). The data indicate that an increase in the number of roots tends to produce shorter roots, except in the treatment without IBA.

The root induction process comprises four stages: priming, initiation, root pattern formation, and root emergence (Yu et al., 2017). Several studies have reported the successful use of IBA in various plant species. According to Yeshiwas et al. (2015), applying 1.000 mg L^{-1} IBA significantly impacted the number and length of roots in rose stem cuttings. Erdiansyah et al. (2016) reported that 4.500 mg L^{-1} IBA applied to Liberica coffee (*Coffea liberica* W. Bull Ex. Hier) resulted in roots 4.97 cm long. Similarly, 4.000 mg L^{-1} IBA produced the longest roots (4.85 cm) in tea (*Camellia sinensis* L.) (Hoque, 2016). Applying 100 mg L^{-1} IBA also produced the longest roots (26.25 cm) and the highest number of roots (6.7) in mulberry cuttings (Sourati et al., 2022). Additionally, 500 mg L^{-1} IBA produced the longest roots (39.5 cm) in Epipremnum aureum stem cuttings (Attanayake et al., 2023). These varied studies show that the effectiveness of IBA concentrations is highly species-dependent.

IBA stimulates the expression of many genes involved in root induction. For example, wounding the plant increases the expression level of the VvPRP gene, which plays a crucial role in altering the mechanical properties of the cell wall, allowing root emergence (Thomas et al., 2003). Optimal concentrations of IBA significantly influence cell metabolism, affecting both molecular and morphological

Table 2. Root length and number of roots at 12 weeks after planting

IBA Concentration(mg L^{-1})	Root length (cm)	Number of roots
0	4.23± 1.7	3.58 ± 0.4 b
5	8.03± 1.6	4.80 ± 2.3 b
10	5.33± 0.6	9.27 ± 2.0 a
15	6.91± 1.6	4.93 ± 0.2 b
20	6.65± 2.6	5.47 ± 0.5 b

Note: Numbers followed by the same lowercase letters in different columns are not significantly different based on the 5% DMRT test.

aspects. At the molecular level, IBA regulates the expression of genes associated with root formation. For instance, the PINHEAD/ ZWILLE gene governs auxin transport and the formation of root meristems (Brinker et al., 2004), while the MtWOX5 gene plays a key role in the development of adventitious roots (Chen et al., 2009). Furthermore, there is an increased expression of several genes involved in IAA biosynthesis and adventitious root induction, including IAA-efflux (PIN1), IAA-influx (AUX1/LAX3), ASA1 (ATHRANILATE SYNTHASE-alpha1), and ANTHRANILATE SYNTHASE-beta1 (ASB1) (Fattorini et al., 2017). The miR156 gene also contributes to adventitious root formation (Ye et al., 2020).

Percentage of Shoots, Number of Shoots, and Shoot Height

The IBA concentration did not influence the percentage of shoots, number of shoots, and shoot height. The percentage of shoots ranged from 76.67% to 23.33%, the number of shoots ranged from 1.07 to 1.33, and the shoot height ranged from 5.12 cm to 17.37 cm (Table 3). Lower concentrations of IBA appeared to promote taller shoot growth compared to other treatments. In *A. titanum*, the shoot is essentially a petiole organ that grows like a stem, also referred to as a pseudostem.

The shoot initiation process begins with the division and differentiation of meristem cells in the corm. Initially, the emerging shoot buds are white and eventually turn green as they continue to grow, forming the petiole, rachis, and leaf blades (Figure 1f). The formation of shoots is known to be triggered by cytokinins synthesized in the roots. Several studies have reported that cytokinins act as transcription factors that stimulate genes involved in the division and differentiation of meristem cells. For example, the Wuschel gene expressed in the promeristem stimulates cell differentiation during shoot formation (Yadav et al., 2011). Liu et al. (2018) also reported that the AHK4 and CYCD genes are highly expressed in meristem tissues during cell division.

The optimum IBA concentration significantly influences plant metabolism, impacting both molecular and morphological aspects in the formation of shoots. Optimal auxin levels stimulate shoot growth, as reported by Müller and Leyser (2011) reported that auxin plays a crucial role in the cell elongation process by affecting the synthesis of structural proteins that contribute to cell wall development and regulate elongation at the shoot tip. Additionally, endogenous cytokinins synthesized in the shoots are vital, as they interact with auxins in shoot formation. Cytokinins also play a critical role in cell wall formation during shoot development, activating the expression of the *Tumorous Shoot Development* (TSD1) gene and the Korrigan1 gene, which produce the *Endo-1,4-β-D-glucanase protein* necessary for cellulose synthesis in cell wall formation (Frank et al., 2002; Krupkova & Schmulling, 2009). Furthermore, the enhanced expression of the TSD2 gene, which encodes *S-adenosyl-L-Met–dependent methyltransferase*, contributes to pectin biosynthesis during cell wall construction and organ formation (Frank et al., 2002; Krupková et al., 2007). Cytokinins are also known to influence cell proliferation, endoreduplication, and mitosis by controlling

Table 3. Shoots percentage, number of shoots, and shoot height at 12 weeks after planting

IBA consentration (mg L^{-1})	Shoots percentage (%)	Number of shoots	Shoot height (cm)
0	23.33± 5.6	1.11± 0.2	7.86± 7.5
5	50.00± 30.0	1.07± 0.1	17.37± 2.5
10	50.00± 10.0	1.33± 0.4	5.12± 2.1
15	76.67± 26.6	1.20± 0.2	12.47± 11.3
20	43.33± 30.3	1.22± 0.2	7.50± 7.5

Description: Data are not significantly different based on the F-test at the 5% level.

the transitions from the G1 (Gap1) phase to the S (Synthesis) phase and from the G2 (Gap2) phase to the M (Mitosis) phase, involving Cyclin-dependent kinases (CDKs) and cyclins as subunits. Additionally, cytokinins stimulate shoot initiation by regulating proliferation in the Shoot Apical Meristem (SAM) (Schaller et al., 2014).

The length and width of leaves

The length and width of leaves were not significantly influenced by the concentration of IBA applied. The leaf length ranged from 4.58 cm to 6.92 cm, while the leaf width ranged from 1.35 cm to 4.80 cm (Table 4). Although there was no significant effect, the 10 mg L^{-1} IBA generally produced the longest leaves (6.32 cm) and the widest leaves (4.80 cm).

The increase in leaf size is related to the increase in the number and length of roots, which allows for the optimal absorption of nutrients and water. Karam et al. (2022) reported that rice husk charcoal contains several nutrients such as: carbon, nitrogen, silica, dan iron. Furthermore, charcoal improves to medium physical structure and various other positive attributes. Besides, charcoal is a carbon-rich, porous substance with multiple functional groups that can potentially increase nutrient retention. Additionally, Sphagnum moss possesses unique characteristics such as controlling the pH of its environment, water remediation, and gas exchange, making it an excellent sustainable replacement. Sphagnum moss is home to a unique microbiome, including endophytic growth-promoting bacteria and fungi such as *Pseudomonas*, *Serratia*, *Burkholderia*, *Flavobacterium* and *Collimonas* (McKeon-Bennett & Hodkinson, 2021)

Several macro-nutrients play central roles in plant metabolism: Nitrogen is essential for synthesizing proteins, nucleic acids, chlorophyll, coenzymes, phytohormones, and secondary metabolites (Kusano et al., 2011). Sulfur is assimilated into amino acids such as cysteine, which are used for synthesizing enzymes and coenzymes (Kopriva et al., 2019). Phosphorus: This element is a structural component of

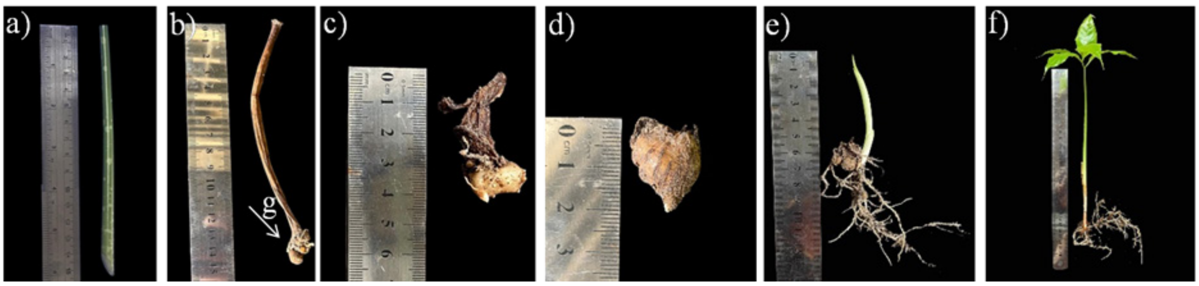

Figure 1. Morphogenesis of *A. titanum* from petiole cuttings.a) petiole cutting as planting material b) petiole begins to shrink at 4 weeks, c) petiole gradually disappears at 6 weeks, d) corm induction observed at 8 weeks, e) shoot formation at 10 weeks, f) seedling development after 12 weeks, g) initiation site visible at 4 weeks

Table 4. Length and width of leaves at 12 weeks after planting

IBA consentration (mg L^{-1})	Leaf length (cm)	Leaf width (cm)
0	4.60± 2.0	1.35± 0.8
5	6.92± 0.7	2.25± 0.3
10	6.32± 1.1	4.80± 3.3
15	4.58± 4.1	2.11± 0.6
20	5.67± 3.8	2.58± 0.5

Note: Data are not significantly different based on the F-test at the 5% level.

nucleic acids and plays a crucial role in energy transfer as a component of adenosine phosphate and in the transfer of carbohydrates between organelles in leaf cells (Malhotra et al., 2019). Magnesium is a component of chlorophyll and is necessary for photosynthesis, the transport of photoassimilates, and protein synthesis (Kwon et al., 2019).Calcium is important for cell wall stabilization and the regulation of osmotic pressure. Potassium regulates osmotic pressure, which is vital for cell expansion, stomatal movement, sucrose translocation, and the rate of water movement driven by mass flow within the plant (Hawkesford et al., 2023).

Furthermore, leaves are sources of endogenous auxin and carbohydrates, which are considered the main energy sources during root formation. Auxin and carbohydrates are translocated from the leaves to the basal wound site on the cuttings, where further interaction between endogenous and exogenous auxin occurs to initiate root primordia formation. Therefore, an increase in the number of leaves will enhance the root number and vice versa (Nasri et al., 2015).

Correlation Analysis

Correlation analysis plays a crucial role in identifying and quantifying the relationships between variables. It helps to understand the strength and direction of these relationships, which can inform hypothesis testing. The correlation analysis of various variables related to the cuttings of *A. titanum* reveals insightful relationships among the variables. The survival percentage shows a very strong positive correlation with the rooting percentage at 0.98, indicating that higher survival rates are closely associated with successful root development. Similarly, survival correlates well with the shoot percentage (0.89), suggesting increased survival rates promote shoot growth.

Root length also demonstrates significant positive correlations with both survival percentage (0.93) and rooting percentage (0.88), further emphasizing the importance of root development in overall plant health. However, corm induction percentage shows weaker correlations with other variables, particularly with root length (0.05), indicating that corm induction may operate independently from root growth parameters. Interestingly, the number of roots has a negligible correlation with survival percentage (0.06), suggesting that merely having more roots does not necessarily translate to better survival outcomes. In contrast, the number of shoots has a strong positive correlation with number of roots (0.87), indicating that increased root numbers may support shoot development.

The correlation between shoot height and other parameters is noteworthy; it correlates positively with survival percentage (0.74) and root length (0.79), indicating that taller shoots

Table 5. Correlation analysis of several variable on morphological traits of *A. titanum*

Variable	SP	RP	SHP	CIP	RL	NR	NS	SH	LL	LW
SP	1.00									
RP	0.98	1.00								
SHP	0.89	0.84	1.00							
CIP	0.36	0.47	0.62	1.00						
RL	0.93	0.88	0.73	0.05	1.00					
NR	0.06	-0.08	0.23	0.01	-0.10	1.00				
NS	-0.11	-0.24	0.26	0.22	-0.28	0.87	1.00			
SH	0.74	0.83	0.41	0.13	0.79	-0.49	-0.73	1.00		
LL	0.40	0.28	0.12	-0.54	0.50	0.48	0.03	0.28	1.00	
LW	0.08	-0.07	0.23	-0.04	-0.06	0.99	0.84	-0.47	0.54	1.00

Note : SP (survival percentage), RP (rooting percentage), SHP (shoots percentage), CIP (corm induction percentage), RL (roots length), NR (number of roots), NS (number of shoots), SH (shoots height), LL (leaf length), LW (leaf width) are associated with better survival and root lengths. Leaf length shows a more complex relationship, as it correlates positively with root length (0.50) but negatively with corm induction percentage (-0.54), suggesting potential competition for resources during the growth phase. Finally, leaf width has a strong positive correlation with number of roots (0.99) and number of shoots (0.84), suggesting that wider leaves are associated with a higher number of roots and shoots, which may enhance overall plant vigor. This comprehensive correlation analysis highlights the interdependence of these variables in the propagation of *A. titanum*, providing valuable insights for future research and conservation efforts.

Among the variables assessed, the shoot percentage and the number of shoots are the most critical criteria for evaluating the success of cutting and propagation. These two parameters directly reflect the plant's ability to regenerate and establish new growth from the cutting, making them essential indicators of successful vegetative propagation. While other variables, such as survival percentage, rooting percentage, and corm induction percentage, are also important, the percentage of shoot formation and the number of shoots provide the most reliable measure of the effectiveness of the propagation process. Thus, these parameters are the most important to monitor for successful propagation.

IV. CONCLUSION

Based on the research, the propagation of *A. titanum* through multiplication using petiole cuttings with various concentrations of IBA has been successfully demonstrated. Among these, 15 mg L^{-1} IBA emerged as the optimal concentration for shoot multiplication that achieved remarkable results: a 100% survival rate, 93.33% rooting success, 93.33% corm formation, 76.67% shoot formation, and an average of 1.20 shoots per cutting. These outcomes highlight the effectiveness of IBA in enhancing the propagation process, providing valuable insights for the conservation and cultivation efforts of *A. titanum*.

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REVIEW OF SOCIAL CAPITAL IN THE SUSTAINABLE FOREST MANAGEMENT

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REVIEW OF SOCIAL CAPITAL IN THE SUSTAINABLE FOREST MANAGEMENT. Social knowledge is a key ingredient in sustainably managing forest resources. It offers an understanding of how people living in forested areas can coexist. Social capital has become a type of community knowledge as far as the matter of community forest management is concerned. Research should be carried out on social capital, which is central role to community-based forest management. This research aims to grasp the theory of social capital, specifically its relevance to communities building a shared identity and engagement to change their managed forests into common "public" spaces, both for the residents and the forest manager. This study uses the literature review method. The findings provide a general understanding of forest management through social capital. The following concepts provide a basic understanding of forest management linked with social capital: 1. Social capital in forest management. 2. Social capital plays an important role in forest management. 3. Social capital expresses itself in forest management. 4. Social capital in action for the forest. 5. Obstacles and challenges to developing social capital in forest management. 6. The measurement of social capital is applied as a management context. 7. Research on social capital in forest management includes managerial implications. 8. The opportunity and challenge of integrating social capital into forest governance. The conclusion is that social capital is the crucial pillar of the sustainable forest management framework.

Keywords: Social capital, sustainable forest management, collaboration, local communities

TINJAUAN MODAL SOSIAL DALAM PENGELOLAAN HUTAN LESTARI. Pengetahuan sosial merupakan unsur utama dalam pengelolaan sumber daya hutan secara berkelanjutan. Pengetahuan sosial menawarkan pemahaman tentang bagaimana masyarakat di kawasan hutan dapat hidup berdampingan. Modal sosial menjadi salah satu pandangan masyarakat dalam kaitannya dengan pengelolaan hutan. Penelitian mengenai modal sosial yang memainkan peran sentral dalam pengelolaan hutan berbasis masyarakat harus dilakukan. Tujuan dari studi literatur ini adalah untuk memahami teori modal sosial, khususnya relevansinya dengan komunitas yang membangun identitas dan keterlibatan bersama untuk mengubah hutan yang mereka kelola menjadi ruang "publik" bersama baik bagi warga maupun pengelola hutan. Penulisan ini menggunakan metode tinjauan pustaka. Temuan literatur menguraikan pemahaman umum mengenai pengelolaan hutan melalui modal sosial dengan pengertian dasar pengelolaan hutan dengan modal sosial: 1. Modal sosial dalam pengelolaan hutan. 2. Modal sosial berperan penting dalam pengelolaan hutan. 3. Modal sosial terwujud dalam pengelolaan hutan. 4. Modal sosial dalam aksi untuk hutan. 5. Hambatan dan tantangan pengembangan modal sosial dalam pengelolaan hutan. 6. Pengukuran modal sosial sebagai konteks manajemen diterapkan. 7. Penelitian mengenai modal sosial dalam pengelolaan hutan mencakup implikasi manajerial. 8. Peluang dan tantangan pengintegrasian modal sosial dalam tata kelola kehutanan. Kesimpulannya adalah modal sosial merupakan pilar penting dalam kerangka pengelolaan hutan lestar.

Kata kunci: *Modal sosial, manajemen hutan berkelanjutan, kolaborasi, komunitas lokal*

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I. INTRODUCTION

Forest management uses a community-based approach, with the primary focus on community involvement and the development of social relationships. However, problems persist, such as deforestation, ineffective collaboration, and limited resource management. Social capital is a fundamental element of modern sustainable forest management (Puspita, Qurniati, & Febryano, 2020). Researching the topic of social capital is critical as this helps address these problems and fosters cooperation. Social capital refers to the trust, networks, and shared norms within a society, facilitating cooperation and collaboration among community members (Putnam, Leonardi, & Nanetti, 1992; Baggio et al. 2016). Social capital is one of the most significant factors in both notifying society about the environment and provoking changes in human views on protecting the environment. Communities and forest managers can use social capital to enhance environmental awareness and protection efforts. This collaboration strengthens relationships, minimizes costs and enhances efficiency (Savari & Khaleghi, 2023; Lee, Rianti, & Park, 2017).

In addition, specific actions within forest management that focus on social capital can foster innovation how people view and interact with the environment in cost-effectively (Mavhura & Mushure, 2019). Such mechanisms show that if social capital is used, it will grow community capacity and help to change practices related to unsustainable forest management such that they become more sustainable (Marizu, Ayiti, & Raufu, 2024).

Reinforcing strong family and friendship ties is a process that eventually produces multiple benefits. If the collaboration between forest-land managers and local communities is undertaken correctly, the outcomes will have positive consequences. Subsequently, this would lead to more reliable information transfer, easier communication, and a higher teamwork success rate. Facilitating the development of effective relationships between communities and forest managers could be achieved by identifying the related issues and addressing them appropriately (Dassir & Mas'ud, 2020). This requires a clear identification of the issues and sustained efforts to address them.

Deforestation remains one of the most pressing threats to forest management. The forest environment has suffered from the dire threat of deforestation. Social capital is one of the major resources to mitigate these ill effects. We should promote stakeholder participation and cut costs to prevent deforestation from becoming a dangerous problem. According to Savari and Khaleghi (2023), social capital works as a defense against damage to the forest.

Recognition of the role played by social capital in natural resources management has increased over time. This awareness can be proved by the escalation of the components of social capital (Bouma et al., 2020). To affect this, forest managers must understand that social capital plays a significant role in forest management and strive to build good social connections with people in the region (Arts et al., 2021). The appropriate use of social capital in community-based forest management is critical in enhancing sustainability and profitability. In the context of sustainable development, cooperatives and social programs play essential roles in enhancing community welfare by supporting economic activities and promoting practices that protect the environment (Liu et al., 2014).

A literature review article on social capital is needed because it would assist in compiling research findings related to the effects of social capital. These include trust, social networks, and collective norms, and they cover different spheres, including resource management, sustainability, and environmental conservation. In managing forests and other natural resources, social capital has the critical function of enhancing cooperation between communities and managerial bodies; this, in turn, develops better sustainability-related practices (Snyder, 2019; Pretty, 2020).

This paper explores in depth the reasons why social capital affects forestry management. The review begins by creating a basic definition of social capital within forest management systems. Second, it classifies different elements of social capital present in forest communities to understand their functions in promoting efficient management practices. The paper analyzes multiple case studies to reveal practical approaches for implementing social capital in actual forest management practices. The review presents the problems and barriers that forest communities encounter when boosting their social capital. The review explores different assessment methods used to measure social capital for forest management purposes and examines how they evaluate effectiveness and practical constraints. The paper studies how social capital research outcomes influence policy choices through decision processes in forestry management. This paper explores the obstacles and opportunities shaping forest management practices when integrating social capital over the upcoming years. Finally, this review explores comprehensively the association between social capital and forest management to determine its capability to maintain forestry operations.

II. MATERIAL AND METHOD

The first step of writing a review article on the role of social capital in natural forest management was to conduct a thorough literature search and analysis. This involved using multiple academic search engines such as ScienceDirect (through the site: www.sciencedirect.com), Google Scholar (https://scholar.google.com/), Scopus (https://www.scopus.com), Jstor (https://www.jstor.org), ResearchGate (https://www.researchgate.net/), and Taylor & Francis (https://www.tandfonline). The following search keywords were employed: "understanding social capital in the context of forest management," "the importance and function of social capital in forest management," "the construction of social capital in forest management," "realistic examples of social capital application in forestry management plans," "challenges and obstacles to the integration of social capital in forest management," and "implications for policymaking".

The study topic was defined early in the process, with a clear focus on social capital within the framework of forest management. The inclusion criteria required studies to be peer-reviewed, published between 2000 and 2024, written in English or Indonesian, and directly addressed the intersection of social capital and forest management. Studies were excluded if they lacked relevance to the forest sector, focused solely on unrelated social theories, or were inaccessible in full text. After screening 199 relevant publications, 80 studies were selected for their contribution to the thematic categories of the review. These studies examined different dimensions of social capital, including its forms, applications, and impact on forest governance. A thematic coding process was applied to classify the content into eight core themes, using an inductive approach based on recurring patterns in the literature. This coding enabled a structured synthesis of the findings. The review integrates interdisciplinary insights from social sciences to improve the implementation of sustainable forest management in local community contexts.

III. RESULT AND DISCUSSION

This study focuses on the integration of social capital into forest management across eight primary themes: the demystification of social capital, social capital in action, classification of social capital, case perspectives, issues in development, quantifying social capital, repercussions of social capital, and looking into the future. Based on our review of 199 publications, we chose 80 articles representing these themes, as outlined in Table 1.

Table 1 presents a comprehensive summary of the key themes and authors contributing to understanding social capital in forest management. **Each of the eight themes is addressed in a dedicated review section,**

combining theoretical foundations with empirical evidence. The analysis includes various expressions and applications of social capital, **evaluates the challenges of integration, explores measurement strategies, discusses the implications for governance, and outlines prospective trends**. This systematic structure enables a holistic view of how social capital contributes to sustainable forestry, thus serving as a foundation for future academic inquiry and policy development.

1. Understanding Social Capital in Forest Management

Social capital consists of three elements: an economic community tied to trade, rules, and trust. However, theoretical frameworks reveal that social capital operates within structured social spaces where different actors compete for forest resources and recognition. The deeply ingrained practices of forest-dependent communities, formed through historical experiences, shape how they perceive and interact with forest resources (Putnam, Leonardi, & Nanetti, 1992). Specifically, social cohesion, social control, and social trust are considered the building blocks of a community (Bourdieu, 2018; Aldrich & Meyer, 2015). Additionally, institutional analysis frameworks reveal that social capital becomes both an input to and output of well-designed institutions, particularly when communities possess clearly defined resource boundaries and appropriate collective choice arrangements (Arts et al., 2021). Consequently, social capital drives community unification and goal achievement (Lee, Rianti, & Park, 2017). Furthermore, social capital stands out in forest management as an indispensable component of the whole process through stakeholder collaboration and a reduction in transaction costs.

Table 1. Summary of Research Across Eight Key Journal Discussions Topics

THEME	AUTHOR	TOPIC
1. Understanding Social Capital in Forest Management	(Bourdieu,2018)	Social capital strengthens community bonds.
	(Aldrich & Meyer,2015)	Social ties enhance community resilience.
	(Górriz-Mifsud, Secco, & Pisani, 2016)	Social capital facilitates forest governance.
	(Baynes et al., 2015)	Community forestry enhances social capital & Social capital fosters ecological problem-solving.
	(Wehi & Lord, 2017)	Cultural practices support ecological restoration.
	(Situmorang 2018)	Social capital strengthens forest management.
	(Lee, Rianti, & Park, 2017)	Social capital enhances collaborative decision-making & Social capital fosters community recovery.
	(Savari & Khaleghi, 2023)	Social capital reduces damage from deforestation.
	(Castaneda et al., 2015)	Social capital addresses environmental challenges.
	(Newton et al., 2016)	Forest communities rely on collaboration
	(Ambio, 2023)	Social interaction strengthens forest resilience.
	(Puspita, Qurniati, & Febryano, I. 2020)	Social capital supports forestry collaboration.
	(Musavengana & Kloppers, 2020)	Social capital fosters local collaboration.
2. The Role of Social Capital in Forest Management	(Lee, Rianti, & Park, 2017)	Social capital enhances collaborative decision-making.
	(Savari & Khaleghi, 2023)	Social capital reduces damage from deforestation.
	(Kim, 2018)	Social capital enhances collective action.
	(Mavhura & Mushure, 2019)	Indigenous knowledge aids resource conservation.
	(Baynes et al., 2015)	Social capital fosters forest conservation.
	(Ido, 2019)	Social capital enhances conflict resolution.
	(Polach et al., 2015)	Social capital supports resource management.

Tabel 1. Continued

THEME	AUTHOR	TOPIC
3. Types of Social Capital in Forest Management	(Woolcock & Narayan, 2020)	Social capital strengthens social ties.
	Górriz-Mifsud, Secco, & Pisani, 2016)	Social networks enhance forest governance.
	(Kleef, Gelfand, & Jetten, 2019)	Collaborative networks enhance forest management.
	(Ihemezie et al., 2021)	Social norms shape conservation behavior.
	(Rousseau et al., 2018)	Human values shape conservation behaviors.
	(Castañer & Oliveira, 2020)	Trust enables effective collaborative management.
	(Roslinda, Ekyastuti, & Kartikawati, 2017)	Social capital supports forest management.
	(Putnam, Leonardi, & Nanetti, 1992)	Social capital enhances civic engagement.
	(Coleman, 1986)	Social capital facilitates cooperative action.
	(Musavengane & Simatele, 2017)	Social capital fosters resource collaboration.
4. Case Studies: Integrating Social Capital into Forest Management	(Colavito, 2017)	Social capital enhances adaptive governance.
	(Vainio, Paloniemi, and Hujala, 2018)	Social networks enhance the success of conservation.
	(Savari & Khaleghi, 2023)	Social capital fosters collective conservation.
	(Dassir and Mas'ud, 2020)	Social capital boosts forest conservation.
	(Fischer et al., 2023)	Community governance enhances forest resilience.
5. Challenges and Obstacles in Developing Social Capital in Forest Management	(Barnes et al., 2017)	Social networks strengthen environmental outcomes.
	(Sterling et al., 2017)	Stakeholder engagement improves biodiversity conservation.
	(Toda, Hashiguchi, & Hiratsuka, 2023)	Human resources enhance forest management.
	(Poteete & Ostrom, 2015)	Conflict limits collective action strategies.
	(Stern & Coleman, 2015)	Trust fosters collaborative resource management.
	(De Vente et al., 2016)	Trust enhances participatory decision outcomes.
	(Lutter, Dayer, & Larkin, 2019)	Trust boosts the persistence of conservation programs.
	(Shirk et al., 2018)	Effective communication fosters community participation.
	(Montoya, Vizuete, & Marcu 2023)	Communication enhances growth in the forestry sector.
	(Borg, Toikka, & Primmer, 2015)	Social capital strengthens collaborative governance.
	(Sténs et al., 2016)	Shared goals strengthen forest governance.
	(Vítková, Dhubháin, & Pommerening, 2016)	Training reduces uncertainty in forestry management.
6. Measuring Social Capital in Forest Management	(Ido, 2019)	Social capital drives collective action.
	(Lestari, Kotani, & Kakinaka, 2015)	Surveys assess social capital participation.
	(Hwang, & Stewart, 2017)	Interviews uncover levels of social capital.
	(Santosa, Setyowati, & Wibowo, 2023)	FGDs enhance social capital dialogue.
	(Cottafava, & Corazza, 2020)	Participatory mapping strengthens stakeholder collaboration.
	(Damstuti & Groot, 2018)	Participatory mapping strengthens stakeholder relationships.
	(Leppin et al., 2014)	Social network analysis strengthens collaboration.
	(Chan, 2018)	Social network analysis enhances relationships.

Tabel 1. Continued

THEME	AUTHOR	TOPIC
7. Policy Implications of Social Capital Research in Forest Management	(Puspita, Qurniati, & Febryano, 2020)	CBFM promotes sustainable forest management.
	(Duguma et al., 2018)	CBFM fosters sustainable development practices.
	(Musavengane and Simatele, 2016)	Social capital supports collaborative management.
	(Bennett, Ravikumar, & Cronkleton, 2018)	Balanced power distribution improves forest management.
	(Laktić, Žiberna, Kogovsek, & Malovrh, 2020)	Participatory processes enhance the growth of social capital.
	(Tang et al., 2021)	Collaborative processes boost perceived outcomes.
	(Musavengane & Kloppers, 2020)	Social capital fosters community resilience.
	(Vítková, Dhubháin, & Pommerening, 2016)	Resource provision enhances social capital.
	(Musavengane & Simatele, 2017)	Resource provision strengthens collaborative management.
	(Young et al., 2016)	Trust resolves conservation conflict effectively.
	(Puspita, 2019)	Social relations benefit forest management.
8. Future Challenges and Opportunities in Integrating Social Capital into Forest Management	(Neal, 2015)	Social capital bridges diverse communities.
	(Thuesen, 2017)	Linguistic diversity influences social capital.
	(Moon, 2016)	Inclusive management fosters diverse work behaviors.
	(Rahman, 2017)	Power imbalance hinders community participation.
	(Pierce et al., 2013)	Social capital aids climate adaptation.
	(Yoo & Lee, 2016)	Flexibility supports social capital management.
	(Gavilanes, Castillo, & Marcu, 2023)	Technology enhances social capital interaction.
	(Amini, Nasrabadi, & Heydari, 2015)	Education enhances social capital development.
	(Fatimatuzzahroh, Hadi, and Purnaweni, 2021)	Local involvement builds social capital.
	(Pairunan, Dassir, & Paembonan, 2021)	Social capital supports sustainable forestry development.
	(Deepak, Wisner, and Benton, 2016)	Technology enhances social capital development.

Building social capital is essential for the implementation of sustainable forest management plans. Indeed, an eco-effective social capital formation technique can be considered an effective strategy for accepting forest management practices that correspond to environmentally friendly principles. The power of social capital is substantial in shaping individual visions regarding forest conservation. This explains why local participation in sustainable forest management is crucial (Górriz-Mifsud, Secco, & Pisani, 2016). Such sustainable forest management has tremendous social and ecological effects.

For instance, Community-Based Forest Management (CBFM) can improve social capital through participation at the individual and community levels in decision-making about forest resources (Baynes et al., 2015). CBFM succeeds by not merely building networks but also restructuring power relations within governance systems, giving communities greater control, and simultaneously building on existing traditional practices and knowledge systems (Wehi & Lord, 2017; Situmorang, 2018). Furthermore, Culturally, CBFM help restore cultural traditions and make landscapes sustainable for future natural resource conservation (Wehi & Lord, 2017)To achieve this, collaboration between forest manager and with the local community should be enhanced. Growing social connections yields elevated trust, better communication, and the formation of collaboration networks (Situmorang, 2018). Social capital ties could be used to structure a more succinct framework of sustainable forest management (Lee, Rianti, & Park, 2017).

Developing social capital not only reduces deforestation. In fact research proves that employing social capital can significantly reduce damage through deforestation (Savari & Khaleghi, 2023) by generating communal action and cost-effectiveness inadressing deforestation. This occurs through collective action mechanisms, where communities with strong internal cohesion, cross-group connections, and links to formal institutions can more effectively monitor forest resources and enforce rules (Ido, 2019). Moreover, research consistently demonstrates social capital's effectiveness in addressing societal challenges (Castaneda et al., 2015). For example, in sustainable forest management, social capital enables communities to coordinate decision-making, disseminate information, and collaborate to address ecological problems (Newton et al., 2016).

Social capital has become a central focus for natural resource manager. This highlights the importance of forest managers acknowledging the enormous role of social capital in safeguarding sustainable forest management (Baynes et al., 2015. This involves placing greater value on the social interaction within and between communities surrounding forest (Ambio, 2023).

Over time, the growing emphasis on social capital reflects its increasing value in forestry processes.Through collaboration, cooperation builds an environmental management system that is optionally adaptable and a prolonged sustainable forest management plan (Puspita, Qurniati, & Febryano, 2020). Engaging in social capital is a process that seeks to rebuild trust, create communication channels, and ultimately make a wider group of citizens participate. As forest management becomes more comprehensive, managers have increasingly attempted to develop social capital, helping to establish relationships with locals (Musavengana & Kloppers, 2020).

2. The Role of Social Capital in Forest Management

Social capital is a key factor that contributes to forest governance systems. Through frameworks of social-ecological systems, social capital functions as a connecting mechanism enabling effective governance across multiple scales, from local forest user groups to regional policy networks (Bouma et al., 2020; Arts et al., 2021). In this context, it has different roles in forest conservation, such as bonding, bridging, and linking social capital. We found that bonding social capital is highly important in dealing with conflicts and strengthening cohesion within a close-knit group in forest management. However, institutional research reveals that internal cohesion alone is insufficient; it must be complemented by connections across diverse groups and links to formal institutions, aligning with polycentric governance in which multiple authorities interact to manage common-pool resources. Bridging social capital mobilizes different and distinct groups for broader cooperation, while linking social capital encourages cooperation between a certain community and other bodies, including governments or NGOs. Community management of resources reduces resource inefficiency (Lee, Rianti, & Park, 2017).

1. The existence of social capital is likely to improve the chances of forest conservation initiatives. Its effectiveness depends on institutional design principles, including clearly defined boundaries, congruence between rules and local conditions, collective choice arrangements, monitoring systems, graduated sanctions, conflict-resolution mechanisms, recognition of organizing rights, and nested enterprises (Musavengane & Simatele, 2017). Bonding social capital, constructed through familial and reciprocally obligatory relations, facilitates the organization of collectivized action for solving crimes in the forest, such as timber

thefts, unlawful hunting. Local communities that share strong social relationships can report illegality cases, such as illegal logging or hunting endangered species, enabling the authorities to take the necessary action. Recent research confirms that a sustainable approach to forest management is essential (Savari & Khaleghi, 2023; Mavhura & Mushure, 2019; Kim, 2018)

2. Social capital enables common interests among stakeholders to be managed. This reflects insights about shared mental models and trust in collective action. However, attention must be directed to power dynamics and potential elite capture, whereby more powerful actors appropriate collective benefits (Ido, 2019; Polach et al., 2015). Bridging social capital supports the interchange of contacts, information, and resources between forest managers, local people, and other related communities to accommodate a common goal. Actors of the forestry sector include forest managers, local residents, and other related bodies (Baynes et al., 2015).
3. Social capital can de-escalate conflict. Research emphasizes that social capital provides a relational foundation for conflict-resolution mechanisms, but institutional design determines whether conflicts are resolved constructively through accessible, low-cost forums for addressing disputes (Young et al., 2016; De Vente et al., 2016). Through connections with external institutions, linking social capital supports conflict mediation and enhances resource management practices.
4. The appreciation of social capital in forestry management by forest managers has increased in recent years (Ido, 2019).

Social capital ranks high in building synergy among stakeholders, lowering the expenses associated with business transactions, and making it easier to initiate joint action in forest governance. Social capital gathers groups interested in reaching a common purpose, as depicted in Figure 1.

3. Types of Social Capital in Forest Management

The research by Woolcock and Narayan (2020) indicated that social capital is essentially aimed at developing social ties. The integration of capital theory reveals that social capital interacts with economic capital (financial resources), cultural capital (knowledge and

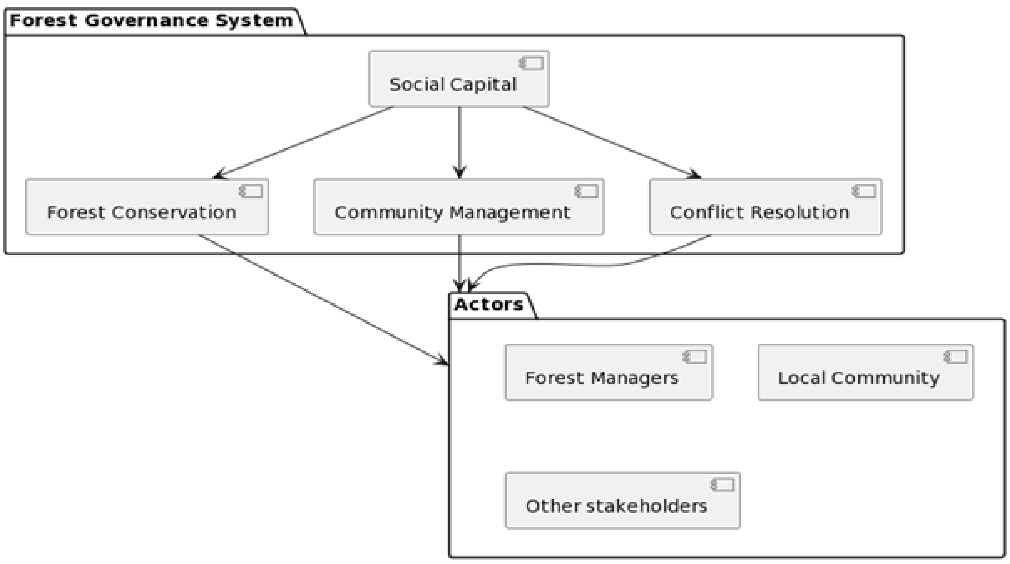

Figure 1. Role of Social Capital in Forest Management (Adapted from: Baynes et al., 2015; Ido, 2019; Lee et al., 2017)

skills), and symbolic capital (recognition and legitimacy) in specific institutional contexts (Bourdieu, 2018). These ties are characterized by durable, resilient bonds that create a strong foundation for trust and cooperation. Having strong social ties is not an end in itself but a bond that can lead to the formation of strong connections and alliances. Social capital is the facilitator of interaction among individuals belonging to a social entity, which makes possible collective activities and coordination of the system (Coleman, 1986). Social capital can be developed implicitly, through informal networks and trust, and explicitly, through organized efforts and formal agreements.

1. Social Networks: Górriz-Mifsud et al. (2016) identified social networks as the complex interconnections of individual and community group members. An established network provides an urgent basis for forest governance. However, their effectiveness depends on institutional arrangements that support information flow and collective action within polycentric governance frameworks that span multiple scales and connect different types of actors (Kleef, Gelfand, & Jetten, 2019). Such networks empower rapid and smooth interaction, encouraging the sharing of critical information and coordination. Social networks grant even forest managers the chance to foster more substantial congruence in the local communities. Social networks are the next steps in furnishing forest management with more effective and efficient methods (Henriksen et al., 2023).
2. Social Norms: Social norms are unwritten codes and behaviors that individuals in groups or society should follow (Kleef, Gelfand, & Jetten, 2019). Research reveals that norms function as informal institutions but must be supported by formal rules and enforcement mechanisms, with their effectiveness depending on their congruence with formal rules and alignment with community values (Ihemezie et al., 2021; Rousseau et al., 2018). Their character may form social norms concerning an individual's attitude toward forest conservation and their tendency to get involved in forest management. The rise of stringent social norms and conservation by community members leads to more caring and active sustainable forest management practices (Ihemezie et al., 2021).
3. Trust: Trust is the confidence that a person has in the predictability and truth of another person's actions (Rousseau et al., 2018). Analysis suggests that trust emerges through repeated interactions under well-designed institutional arrangements that provide information about the behavior of others and create incentives for cooperation (Lutter, Dayer, & Larkin, 2019). This factor is paramount in determining whether forests are managed sustainably, since it brings about cooperation and collaboration between many different entities. Effective collaboration between forestry managers and locals can only be achieved by nurturing mutual trust and partnerships. Trust commonly enables cooperation in strategy planning to effectively manage forests and ecosystems (McIntyre and Schultz, 2020).
4. Cooperation: Cooperation means collective work by individuals or groups who move formally and orderly to perform the same things to reach their mutual goals (Castañer & Oliveira, 2020). The role of collaboration in forest management is striking because it can be a game changer for the efficacy and resilience of forest management methods and the livelihoods, well-being, and sustainability of stakeholders. For example, consultation between forest agents and people living in the vicinity of the forest is needed when both parties are involved in drafting forestry strategies, with everyone's needs and interests taken into consideration.

Social capital may be an umbrella term that involves relationships, institutions, social norms, trust, and cooperation. Field analysis reveals how power relations influence the distribution and effectiveness of different forms of capital, while institutional analysis shows how rules and norms shape incentives for collective action (Bourdieu, 2018). These different types of social capital are some of the eminent features of development management as they support dialogue, the communication of information, synergy and the establishment of better decision-making techniques (Roslinda, Ekyastuti & Kartikawati, 2017; Putnam, Leonardi & Nanetti, 1992; Coleman, 1986). Understanding all these different types of capital and how they impact the management process is essential before any significant effort is made in that particular direction. Social capital is, therefore, a key to the welfare of both people and natural resources (Musavengane & Simatele, 2017).

4. Case Studies: Integrating Social Capital into Forest Management

Social capital must be supported by any forest management intervention where communities are actively engaged. In such cases, the primary role of social capital is its capability to enhance the level of cooperation and trust between the direct actors. Analysis through institutional design frameworks reveals how social capital development occurs within specific power structures and governance arrangements (Colavito, 2017; Fischer et al., 2023). Here are some case studies from various countries that report the practice through some good examples of how social capital plays a role in forest management.

1. The United States, particularly in western states such as Arizona, Colorado, New Mexico, and California, emphasizes social capital as a critical determinant of effective collaborative forest rehabilitation. These programs illustrate polycentric governance principles by creating institutional arrangements that connect multiple scales of governance while addressing power imbalances within forest management systems, which include federal agencies, local communities, environmental groups, and industry actors (Colavito, 2017). Such programs emphasize the importance of stakeholder engagement; mutual understanding; cooperation between federal agencies, communities of interest, and other stakeholders; and the regulation of the social system. Social capital improves adaptive governance through people's networking and ensuring that pertinent scientific knowledge is incorporated into the decision-making processes. Continuously sustained, face-to-face contact is crucial for these kinds of relationships to overcome tasks such as schedule discrepancies and allow the direct translation of scientific knowledge into the context of forest management (Colavito, 2017).
2. In Finland, the Collaborative Forest Landscape Restoration Program (CFLRP), a successful case of forest conservation, is discussed by having a look at the forest owners' personal goals and their social circles. The case demonstrates how social capital operates within existing institutional frameworks, whereby the behavior of forest owners depends on not only personal motivations but also their position within social networks and access to different forms of capital. The final result is that having clear, robust conservation objectives and qualified social capital positively predicts the level of conservation management. Social networks are essential for information provision, collaboration, and support in tackling conservation challenges. The study shows that these motivational aspects matter for successful conservation, as does the access of social capital forest owners have in forest conservation networks (Vainio, Paloniemi, and Hujala (2018).
3. Research being carried out in Brazil proves the role social capital plays in organizations that aim to conserve forests. The case illustrates how social capital addresses problems related to collective action in

deforestation control. However, analysis reveals that effectiveness depends on broader institutional reforms that address how the positions of different actors within governance systems influence their ability to benefit from social capital development. Deforestation management was discussed in this critique as something that can be successful through a form of social capital that causes collective action and, simultaneously, reduces administrative costs (Savari & Khaleghi, 2023).

4. A case study in Indonesia demonstrates that social capital significantly impacts individual involvement in forest conservation efforts. The case shows how traditional governance systems can be strengthened through institutional innovations that build on existing social capital, with effectiveness depending on addressing conflicts between traditional and formal governance systems while respecting community cultural practices. As social capital has built-in family and group norms and beliefs that promote community engagement in and individual contributions to the conservation of forests, social capital is one of the main reasons for this type of participation (Dassir and Mas'ud, 2020).
5. The Community Forest Governance program described by Fischer et al. (2023) is dedicated to India's tropical forests and demonstrates that indigenous and rural people can actively participate in forest resource management. The case illustrates institutional design principles: communities develop clear boundaries around forest resources, create rules matching local conditions, establish collective choice arrangements, implement monitoring systems, and connect to broader governance networks. This linkage is associated with results in enhanced carbon storage, biodiversity, and rural income generation. In addition to the ecosystem improvement, the program empowers forest management associations and local rule-makers to improve the socio-economic returns. The review shows that enhanced community decentralisation in the use of forests ensures better forest and ecosystem resilience.

These cases reveal that social capital development is most effective when it occurs within institutional frameworks that address power imbalances, provide multiple pathways for participation, and create mechanisms for adaptive management. The main thing is that associated social capital development will lead to sustainable development; this comes down to forest management. Forests are the primary source of goods and services for local communities, and they impact the preservation of our overall global environment. It has been found that one of the factors behind this impact is social capital resonance. Consequently, social capital makes the simultaneous implementation of sustainability and forest utilization initiatives possible. Social capital helps fulfill the reliable functioning of forest management activities without violating a community's ecological, social-economic, and environmental belonging. The key to addressing the demands of climate change is the improvement of social capital, in terms of engaging local communities, promoting environmental education, and involving all stakeholders to come up with new, resilient ideas. Social capital allows conservation and forest utilization management approaches to be implemented in alternative and synchronized ways.

5. Challenges and Obstacles in Developing Social Capital in Forest Management

Creating a solid rapport between the authorities responsible for forest governance and the community is key to accomplishing the right forest conservation practices. Understanding these challenges requires institutional analysis that reveals how structural constraints limit collective action possibilities, from individual relationships to broader political systems shaping forest governance (Sterling et al., 2017). Equally, however, there are several difficulties in using collaborative management to reinforce social relations. Some of the obstacles that arise during efforts to increase social capital in the context of forest management include:

1. Creating reliable social capital that affects dispute situations is challenging in problematic groups. Building trust occurs within systems that are characterized by power imbalances and historical conflicts, where external interventions can undermine efforts when they fail to recognize local knowledge systems. The trust and social connections that are very important between forest managers and communities cannot be built in one night (Poteete & Ostrom, 2015).
2. Obstacles that conflict with key stakeholders, including stakeholders' contrasting interests, may be a major challenge to creating sustainable social capital and implementing a sustainable forest management strategy. Analysis suggests that conflicts often arise from poorly designed institutions that create perverse incentives or fail to align rules with local conditions (Toda, Hashiguchi, & Hiratsuka, 2023). Through the empirical studies by Sterling et al. (2017), we will find out how these conflicts can occur due to the differing perspectives of local people toward the forest and the approaches taken by forestry management.
3. Structures like governance and human resources are essential pillars in building social capital. Research emphasizes that effective collective action requires social capital, technical knowledge, financial resources, and organizational capabilities. Human resources are important in developing strategies for effective forest management. In many low-income countries, limited financial capacity leads to a shortage of skilled human resources, which hinders the development of robust forest management strategies (Toda, Hashiguchi, & Hiratsuka, 2023).
4. Mental barriers like misgivings and inadequate awareness could also obstruct social solidarity development. These often reflect rational responses to institutional failures and power imbalances, where communities resist interventions due to their previous negative experiences. The management strategies of the woodland of such communities are highly limited by the prevailing conflict and distrust in the community (Poteete & Ostrom, 2015).
5. Another issue in the constitution of social capital may be that local communities do not take an active role. Limited participation often results from institutional barriers that exclude certain groups, with analysis revealing how different forms of capital influence the ability of communities to participate effectively in forest governance (Bourdieu, 2018). Limited participation will reduce the likelihood of attaining sustainable forest management goals. Under-representation may result in negligible exposure to information, while a shortage of resources can also be the cause (Toda, Hashiguchi, & Hiratsuka, 2023).

Forest managers employ different strategies to mitigate issues through which these challenges can be addressed. These strategies must focus on institutional reforms that support social capital development while addressing structural constraints. In these situations, the management method consists of several stages:

1. Strengthen trust: Several investigations indicate that developing trust is imperative in the relationship formation between forest managers and local units (Stern & Coleman, 2015; de Vente et al., 2016; Lutter, Dayer & Larkin, 2019).
2. Improve communication: Establish effective communication places between forest managers and local communities. The emphasis is on increasing the standing of the forestry sector and fostering its growth by holding effective communication and regular meetings. Regularizing meetings supplies information and education, as well

as actively incorporates people into their understanding and forest management processes (Shirk et al., 2018; Montoya, Vizuete, & Marcu 2023).

3. Common goal: Boost social capital and encourage proper forest management rules. Stakeholders are requested to put into practice all their different points of view. Mutual agreement may occur by settling on shared goals and making joint efforts to find solutions that benefit everyone (Borg, Toikka, & Primmer, 2015; Sténs et al., 2016).
4. Provision of resources: To deliver this message, specialists stress that offering the necessary resources, like training and technical assistance, can prevent structural barriers, creating the possibility of good forest management (Vítková, Dhubháin, & Pommerening, 2016).

Social capital plays a prominent in promoting sustainable forest management and ensuring that both nature. Social capital is the capacity to build and maintain durable and successful forestry schemes

6. Measuring Social Capital in Forest Management

It is important to assess social capital to capture its significance in forest management and design effective processes for increasing that capital (Ido, 2019). Measuring social capital requires methodological approaches that capture both structural and cognitive dimensions while recognizing the institutional contexts that shape the effectiveness of social capital (Lestari, Kotani, & Kakinaka, 2015; Hwang & Stewart, 2017). An outline of the methodologies and tools used to assess social capital in the field of forest management is as follows:

1. Surveys: Forest supervisors use surveys to assess and describe social capital. However, their effectiveness depends on these officers' understanding of local contexts and power relations, with institutional analysis suggesting that questions should examine not only trust and networks but also institutional arrangements that support collective action. Surveys are used to gain information about social networks, perceptions, and social norms (Lestari, Kotani, & Kakinaka, 2015).
2. Interviews: Interviews are done to unearth different levels of social capital. Semi-structured interviews can explore how social capital operates in specific institutional contexts, examining the experiences of community members regarding collective action and their understanding of formal and informal rules. These help develop good coordination between local communities and give managers a way of knowing (Hwang & Stewart, 2017).
3. Focus Group Discussion (FGD): A FGD is considered the most efficient to understand various aspects of social capital. FGDs provide opportunities to observe social capital dynamics while examining how power relations, cultural norms, and institutional arrangements shape group interactions and collective decision-making. It is an excellent tool for stakeholders to conduct decision-oriented interactive dialogue. It is a place where an open and trusting atmosphere can be created. The purpose is to try to bypass barriers and distrust (Santosa, Setyowati, & Wibowo, 2023)
4. Participatory Mapping: This tool ensures the active participation of local community groups in conceptualizing social networks and other forms of social capital. The process can reveal how stakeholders perceive resource boundaries, use patterns, and management responsibilities while building social capital by creating a shared understanding (Cottafava & Corazza, 2020). This method is useful in understanding complex, reciprocal relationships among stakeholders (Damstuti & Groot, 2018).
5. Social Network Analysis (SNA): The use of SNA enables the examination of social relationships to enhance and strengthen those relationships. However, analysis must be interpreted within institutional contexts

that shape network formation, examining how formal and informal institutions influence network development and how power relations affect the positions of different actors. Social networks tend to be made visible as the various process as the various forms of social relationships are examined and parties with key roles are identified (Leppin et al., 2014; Chan, 2018).

Effective measurement requires combining multiple methods within theoretical frameworks that recognize the extent to which social capital is embedded in institutional and power structures. Exploring social capital in forest management is pertinent to realizing its essence in forest management and defining what characterizes successful results that increase social capital. Common research methods such as polls, interviews, FGDs, and participatory mapping are examples of tools used to evaluate social capital in forest management. Forest managers should use the proper way to develop closeness and link community members to their area of work.

7. Policy Implications of Social Capital Research in Forest Management

Active community participation in managing forests can strengthen social capital. The benefits of this positively impact forests, ecosystems, and human life. Policy implications must be grounded in institutional analysis that addresses both opportunities for and constraints on collective action, as well as an understanding of how different institutional arrangements support or undermine social capital development (Duguma et al., 2018). Strategies have been developed to ensure the development of different items of social capital. The following policies involve the integration of social capital:

1. Advocating Community-Based Forest Management (CBFM): CBFM can bridge a social gap. CBFM policies must incorporate institutional design principles while addressing power imbalances, requiring clearly defined resource boundaries and genuine collective choice arrangements rather than consultation opportunities that maintain existing power structures. The integration of CBFM into the current practices can be accomplished by stimulating sustainable forest management practices (Duguma et al., 2018). The level of the country's social capital would be raised with the proper implementation of strategies like CBFM in Indonesia. A well-developed and well-implemented CBFM policy draws positive attention to entire society and the ecosystem (Musavengane and Simatele, 2016).
2. Balancing power distribution: Studies on social capital show that power disproportionality can hinder capital formation. Policies must recognize how different forms of capital influence the ability of communities to participate effectively, requiring genuine power redistribution that involves the transfer of real authority rather than superficial consultation processes. This imbalance results in complications when implementing efficient forest management strategies. Policies are designed to reduce power disparities. The gaps are related to management authority and resource distribution. The equal distribution of power can contribute to more equitable and effective forest management (Bennett, Ravikumar, & Cronkleton, 2018).
3. Supporting participatory decisions: Scientists have shown that when people take part in conflict resolution aimed at finding agreement, the social capital within the community grows. Effective participation requires institutional innovations that enable meaningful engagement rather than stakeholder meetings, with success depending on building social capital through repeated positive interactions. The active involvement of people determines the formulation and implementation of forestry policy (Laktić, Žiberna, Kogovsek, & Malovrh, 2020). Policies that empower joint decision-making processes can strengthen

society to grow socially and even boost positive outcomes. These improvements, which affect individuals and the environment around them, will happen (Tang et al., 2021).

4. Providing adequate resources: Social capital studies prove that community improvement is often achieved by providing resources to the community. Resource provision must address both immediate capacity needs and longer-term institutional development, with financial and technical support strengthening existing community institutions instead of creating parallel structures. Identifying these resources requires offering various forms of education, such as technical assistance. This way of doing things truly has an essential meaning in building social capital. Policies that provide the local populace with resources such as forest management and credit will better promote social capital. Investment in social capital brings positive gains to society and the environment (Vítková, Dhubháin, & Pommerening, 2016); Musavengane & Simatele, 2017).
5. Resolving conflicts of interest: Social capital studies also indicate that conflicts of interest between stakeholders can hinder forming social capital, so policies should be designed to defuse conflict. Effective conflict resolution requires accessible forums that provide legitimate pathways for addressing grievances. However, sustainable resolution also requires the underlying power imbalances and institutional arrangements that create conflicts to be addressed. Once a conflict is resolved, the fair distribution of resources is possible (Young et al., 2016).

Polycentric governance frameworks provide the overarching policy approach for integrating social capital development with effective forest management, recognizing that forest governance occurs at multiple scales and requires coordination among different institutions. Puspita (2019) highlighted that the findings of social capital studies have important policy implications in forest management. Forest officials need to be capable of having tight connections with people in the community and impress people practically about rational forest management. Social relations not only generate profits for the community and managers but also provide long-term environmental benefits. The policies implemented need to focus on spurring the growth of social capital, as presented in Figure 2.

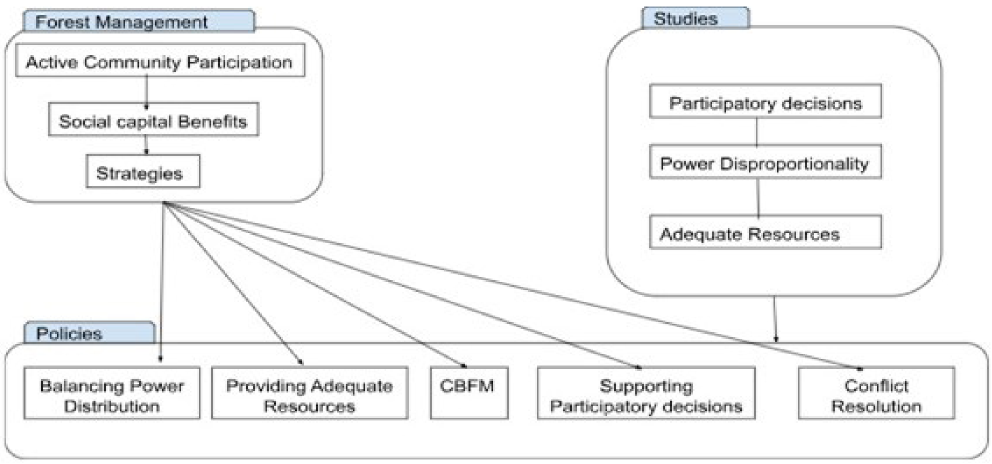

Figure 2. Policy Implications of Social Capital Research in Forest Management (Adapted from: Puspita, Qurniati, & Febryano, 2020; Duguma et al., 2018; Bennett, Ravikumar, & Cronkleton, 2018; Laktić et al., 2020; Tang et al., 2021; Musavengane & Kloppers, 2020; Vítková, Dhubháin, & Pommerening, 2016; Musavengane & Simatele, 2017; Young et al., 2016)

8. Future Challenges and Opportunities in Integrating Social Capital into Forest Management

8.1. Challenges

1. Forming social capital in a diverse society is a challenging and important task. Diversity reflects broader social changes that create both opportunities and challenges, with analysis suggesting that diversity can not only enhance collective action through complementary skills but also create coordination challenges. First of all, individuals of different generations have similar factors. For example, variations in lifestyle, culture, and values exist in society (Neal, 2015). It will be crucial to develop policy measures backed up by the ideas, symbols, and sentiments of a range of diverse perspectives (Thuesen, 2017; Moon, 2016).
2. The issue of power imbalance is a paramount constraint in creating mutual aid networks and developing forest management strategies (Adhikari, Kingi & Ganesh, 2016). Power imbalances represent fundamental structural challenges that constrain social capital development, with field analysis revealing how the positions of different actors in broader political and economic systems influence their forest governance participation. Defeating poverty in such conditions demands policy reform implementation and commitment to change from policymakers (Rahman, 2017).
3. Climate change, social upheaval, and geographic shifts are new and interesting challenges in the formation and management of social capital. These create challenges requiring adaptive institutional arrangements and enhanced collective action capacity, whereby social capital can facilitate adaptive management but uncertainty can undermine it by making stable expectations difficult. Flexibility remains the pivotal trait of an effective strategy that can promptly respond to circumstances that change frequently (Pierce et al., 2013; Yoo & Lee, 2016).
4.
5. Long-term stability depends on directing resources and efforts into building social wealth that will be the foundation of future development and empowerment. This requires institutional arrangements that maintain social capital across generations while adapting to changing conditions, thus balancing continuity with adaptation. Sustainable social wealth depends on social capital existence (Yoo & Lee, 2016). Continuous urgency and hard work are required on the part of forest managers to achieve the organization and durability of social bonds between the managers and local communities.

8.2. Opportunities

1. Technology is one of the major factors that can be tapped to affect social capital construction and maintenance in forest management. Technology creates opportunities for social capital development, but its effectiveness depends on institutional arrangements ensuring equitable access and appropriate use, with digital platforms potentially connecting dispersed communities; nevertheless, digital divides still require attention (Gavilanes, Castillo, & Marcu, 2023). Social media platforms also play a crucial role in this process. Social media enables interaction and collaboration among geographically distant communities with a common interest in environmental management.
2. Education and awareness promotions can also be undertaken by stakeholders in the process of developing social capital. Educational initiatives should focus on developing practical skills while building social capital in different community groups, requiring participatory approaches that augment existing knowledge while creating opportunities for collective learning. Such an ongoing process would benefit communities lacking information about forest management methods (Amini, Nasrabadi, & Heydari, 2015).
3. Supporting local involvement may result in developing social capital and organizations

that can cope better with the challenges of forest management. Local engagement strategies can build social capital by creating meaningful participation opportunities while addressing structural barriers, which requires long-term commitment and genuine power sharing (Fatimatuzzahroh, Hadi, and Purnaweni, 2021). One way of enabling engagement is the application of incentives such as cash awards or character recognition.

4. Methodological advancement: Future work should include qualitative research approaches and quantitative support for analyses, which would enable examinations of social networks, trust dynamics, and collaborative processes (Hwang & Stewart, 2017; Lestari, Kotani, & Kakinaka, 2015). By relying mainly on qualitative-led methodology, this approach can explore the deep cultural meanings behind social capital. At the same time, the use of numerical data would allow results to be validated and applied across diverse forest management contexts (Santosa, Setyowati, & Wibowo, 2023).

The undeniable fact is that social capital is vital for forest management to facilitate the development of sustainable communities and enhance both human and environmental wellness (Pairunan, Dassir, & Paembonan, 2021). Integrating social capital into forest management represents both significant opportunities and complex challenges, necessitating sophisticated institutional analysis and innovative governance arrangements. Even though the development of social capital is impeded by various barriers, there are still plenty of possibilities to utilize technology, education, and awareness promotion, stimulation and engagement, as well as the creation of partnerships, to develop and preserve social capital (Deepak, Wisner, & Benton, 2016).

IV. CONCLUSION

A multidimensional concept encompassing trust, networks, norms, and community participation, social capital serves as a crucial pillar in sustainable forest management. This study of 80 research projects covering eight themes has demonstrated that social capital positively supports forest conservation by bringing different community members together for joint activities. The findings demonstrate that social capital operates through multiple mechanisms: facilitating community participation in governance, reducing transaction costs, strengthening conflict-resolution processes, and building adaptive capacity. Case studies from various countries consistently show that successful initiatives depend on strong social capital that is supported by appropriate institutional arrangements. Trust must be built, differences in influence are often present, insufficient resources are rarely provided, and stakeholders may have different interests. To resolve these challenges, forests need to be managed with CBFM, participatory ideas, and a fairer distribution of power among participants. Policy implications emphasize the importance of institutional design principles that address power imbalances while ensuring genuine collective choice arrangements rather than superficial consultation processes. Several techniques are available for accessing information about social capital in forest communities, such as interviews, surveys, focus group discussions, participatory mapping, and social network analysis. In the years ahead, it will be important to adopt new technologies to include the community more effectively, provide better educational programs, and manage the obstacles caused by growing diversity and climate change. Both the building and use of social capital are important aspects of successful forest governance.

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THE DIVERSITY AND ACTIVITY OF SUBTERRANEAN TERMITES IN THE RESIDENTIAL AREA OF BOGOR, WEST JAVA, INDONESIA

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THE DIVERSITY AND ACTIVITY OF SUBTERRANEAN TERMITES IN THE RESIDENTIAL AREA OF BOGOR, WEST JAVA, INDONESIA. The housing demands in Bogor City have been on the rise, leading to environmental changes affecting pest organisms, especially subterranean termites. This research aimed to identify various species of subterranean termites in Bogor City, analyze soil and weather conditions, and evaluate termite attack frequency and severity. The study spanned 12 designated sub-districts. In each area, 25 bait wood (2 x 2 x 46 cm) crafted from pine wood and treated with water vapor pressure (105°C, 1 bar, 5 hours) were installed. Soil samples were gathered from each sampled village, while weather data was specifically documented in one sub-district. Findings uncovered three termite species inhabiting residential zones of Bogor City: *Microtermes insperatus*, *Macrotermes gilvus*, and *Schedorhinotermes javanicus*, with *Microtermes insperatus* emerging as the predominant species. The soil and weather conditions significantly favored termite existence in Bogor City. Termite attack prevalence stood at 38%, and the degree of wood damage ranged from 4 to 9.

Keywords: Attack frequency, damage intensity, *Pinus merkusii*, Soil characteristics, water pavor presure

KEANEKARAGAMAN DAN AKTIVITAS SPESIES RAYAP TANAH DI LINGKUNGAN PERMUKIMAN KOTA BOGOR, JAWA BARAT, INDONESIA. Kebutuhan masyarakat Kota Bogor akan tempat tinggal semakin meningkat, sehingga mengubah kondisi lingkungan yang dapat memengaruhi keberadaan organisme pengganggu, terutama rayap tanah. Penelitian ini bertujuan untuk mengidentifikasi spesies rayap tanah dan keanekaragamannya di Kota Bogor, mengetahui karakteristik tanah dan cuaca, serta mengetahui intensitas kerusakan dan frekuensi serangan rayapnya. Penelitian dilakukan di 12 kelurahan contoh. Setiap kelurahan ditanam 25 kayu umpan (2 x 2 x 46 cm) dari kayu pinus yang sebelumya telah diberi perlakuan tekanan uap air (105°C, 1 bar, 5 jam). Disetiap kelurahan contoh diambil tanah contoh. Data cuaca diukur di salah satu kelurahan contoh. Hasil penelitian menunjukkan bahwa spesies rayap yang ditemukan ada 3 jenis yaitu Microtermes insperatus, Macrotermes gilvus, *dan* Schedorhinotermes javanicus. *Spesies rayap tanah di lingkungan pemukiman Kota Bogor didominasi oleh* Microtermes insperatus. *Karakteristik tanah dan cuaca sangat mendukung kehidupan rayap di Kota Bogor. Nilai frekuensi serangan rayap sebesar 38% (tinggi) dan nilai intensitas kerusakan kayu adalah 4-9.*

Kata kunci: Frekuensi serangan, intensitas kerusakan, karakteristik tanah, Pinus merkusii, *tekanan uap panas*

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I. INTRODUCTION

Termites play an essential ecological role, but some termites become nuisance pests and destroy buildings (Novita et al., 2020). According to Krishna et al. (2013) there are approximately 3,106 termite species spread worldwide, with 9.7% or about 300 of these species found in Indonesia (Nandika et al., 2015). About 28 termite species have developed outside their native range and are considered invasive (Evans et al., 2012). The massive activity of termites causes high economic losses. Economic losses due to termite infestation in buildings with residential functions in DKI Province (cases in West Jakarta and East Jakarta) are estimated at 66.2 billion rupiah per year, and the economic loss due to termite infestation in residential buildings in Indonesia in 2015 was 8.86 trillion rupiah (Nandika et al., 2015). Termite attacks occur in any type of building containing cellulosic materials. This includes timber-framed residential houses as well as the non-structural wooden elements (e.g., trim, partitions, and cabinetry) found in commercial high-rise buildings (Arinana et al., 2025).

Bogor is one of the major cities in Indonesia. The area of Bogor City is 11,850 ha. The monthly average temperature in Bogor City is 23.2°C (the lowest temperature is 21.8°C and the highest temperature is 37.6°C), with the humidity is 35.3-98.5% (Arinana et al., 2020a; Nurhadi et al., 2023) and average annual rainfall of around 3,000 – 6,000 mm (Tarigan and Dasanto, 2022). Geographically, Bogor City is located between 106’ 48’ East and 6’ 26’ South. The geographical position of Bogor City is in the middle of Bogor Regency. Its location, which is very close to the capital city of Indonesia, Jakarta, has strategic potential for the development and growth of the economy and services. Bogor city also serves as the center of national activities for industry, trade, transportation, communication, and tourism (Ilhami et al., 2022). According to data from Badan Pusat Statistik (2018), the population growth rate of Bogor City from 2010 to 2017 was 1.53%, with a population of 1,081,009 people. The community’s need for housing has increased based on this population growth, thus changing the surrounding environmental conditions. Environmental changes will affect the presence of pest organisms, including termites (Jouquet et al., 2018).

Pest organisms, such as termites, often thrive when natural ecosystems are disturbed by human activities, such as urbanization, which creates favorable new conditions for them. Until now, information on subterranean termite diversity in residential areas of Bogor City is limited. This information is essential for designing strategies to protect buildings from termite infestation in the residential environment. Therefore, research on the diversity of subterranean termites in residential areas representing Bogor City is urgently needed. This study focuses on determining the diversity of subterranean termite species, identifying subterranean termite species that attack bait wood in residential areas in Bogor City, evaluating the environmental factors (soil and weather), and analyzing the intensity of damage and frequency of subterranean termite attacks in Bogor City, West Java, Indonesia.

II. MATERIAL AND METHOD

A. Time and Location

The research was conducted from September 2019 to July 2020. The field portion of the study involved the installation of bait wood samples, which were all placed simultaneously in September 2019 across the 12 sub-districts. These baits were left in the field for a three-month exposure period and were subsequently collected in December 2019. Laboratory activities, including sample processing and termite identification, were carried out from January to July 2020 at several facilities. The test samples were made at the Sawmill and Wood Workshop Laboratory of the Faculty of Forestry and Environment, IPB University. Treatment of bait wood and identification of termite species were carried out in laboratories located in the Wood Quality Improvement Technology Division (TPMK) of the Faculty of Forestry and Environment and the Pilot Plant Laboratory of the Faculty of Agricultural Technology, IPB University (Institut Pertanian Bogor). Soil characteristic testing was conducted at the Indonesian Center for Biodiversity and Biotechnology (ICBB) Bogor. Bait wood installation was conducted in 12 sub-districts in Bogor City, namely Situ Gede, Sindang Barang, Pasir Jaya, Empang, Cikaret, Batu Tulis, Katulampa, Kedung Halang, Tanah Sareal, Sukaresmi, Kebon Kelapa, and Tegallega.

B. Equipment and Materials

The equipment used in this study consists of a circular saw, grinder, autoclave, moisture meter, fan, calipers, digital scales, brushes, soil drill, crowbar, Global Positioning System (GPS), LCD digital temperature humidity data recording logger meter, and digital microscope endoscope camera magnifier 800X 8 LED. The materials used in this study consisted of pine wood (Pinus merkusii) from Cikalancing Cinangneng Housing, oil paint, specimen bottles, plastic clips, 70% alcohol, and sandpaper.

C. Research Sample Area

The study sites were selected using a multi-stage random sampling method. Bogor City comprises a total of 6 districts and 68 sub-districts. First, all six districts were included in the study. From each district, two sub-districts were randomly selected using Excel's randomization function, for a total of 12 sub-districts. Finally, one Neighborhood Association (Rukun Tetangga) from each of the 12 selected sub-districts was randomly chosen as the location for bait wood installation and soil sampling. This method ensured a diverse and representative selection of study sites. Air temperature and humidity data were taken from one of the representative neighborhoods.

D. Preparation of wood Sample Test

Pine (*Pinus merkusii*) logs were obtained from one of the housing estates in Cinangneng Village. The pine logs were cut at sawmills into two-meter-long logs. The logs were brought to the workshop to be sawn into test samples (bait wood). According to the American Society for Testing and Materials (2006), the bait wood size is 2 cm x 2 cm x 46 cm in air-dried condition. Before treatment, the bait woods were sanded to remove the fibers on its surface. The bait woods were given a hot vapor pressure treatment for 5 hours with a temperature of 105°C and a pressure of 1 bar. The hot vapor pressure treatment was used, following the protocol of Arinana et al. (2020b), to reduce wood resin content and standardize the moisture level, which can make the bait more uniformly palatable to termites compared to simple oven-drying. After that, the bait woods were conditioned to air dry and sanded again to remove the resin on the surface. Each bait wood was painted a bright color (red) on one end to make it easier to locate the bait wood after it had been installed for three months. The installation of bait wood refers to Arinana et al. (2022). Before installation at the research site, the bait wood was measured for thickness and weighed (W1) using a digital analytical balance (Ohaus PX224, ±0.001 g).

E. Analysis of Soil Characteristics

The international pipette method was used to investigate soil texture properties (Taghizadeh-Mehrjardi et al., 2021). Soil samples of at least 1 kg were collected in each sample sub-district at 0-25 cm depth. Soil samples were collected from the vicinity of the bait wood installed. All soil samples were then analyzed at the ICBB Laboratory in Bogor for soil characteristics consisting of soil pH, soil C-organic content, and the percentage composition of sand, silt, and clay.

F. Temperature and Humidity Measurements

Temperature and humidity measurements were taken using a Digital Temperature Humidity Data Recording Logger Meter DWL-20 series. The device records air temperature and humidity every five minutes and was placed in one of the sample urban village offices for three months.

G. Termite Species Identification

Identification of subterranean termites was conducted based on the morphology of the soldier caste, following the identification keys from Nandika et al. (2015) and Krishna et al. (2013), the identification of subterranean termites was carried out based on the morphology of subterranean termites.

H. Analysis

The species diversity of subterranean termites in the residential area of Bogor City was approached with the parameters of the index of species richness, index of heterogeneity, and index of evenness. Margalef's formula, as modified by Arinana et al. (2019), was adapted to calculate subterranean termite species richness (*Ri*). Species diversity (*H'*) was calculated by adapting the Shannon-Weiner formula, and species evenness (*E1*) was calculated using the Pielou formula, which also followed modifications suggested by Arinana et al. (2019). The data processed were from all sample sub-districts in Bogor City. The formula is as follows:

$$Ri = \frac{S-1}{ln(N)} \quad \text{....(1)}$$

$$H' = \sum_{i=0}^{S} pi.\ln(pi); pi = \frac{ni}{N} \quad \text{....(2)}$$

$$E_1 = \frac{H'}{In(S)}; \quad \text{....(3)}$$

Description:
Ri: species richness
H': species diversity
E1: species evenness
Pi: proportion of the number of individuals of type *i*
S: number of species
N: Total number of bait wood-infested
ni: number of bait wood infested by the *i*-species

I. Frequency of Subterranean Termite-Infested Bait Wood

Infestation frequency is the ratio of the number of samples infested by subterranean termites at the study site to the total number of samples installed at the study site, expressed as a percentage. Infestation frequency data were averaged per sample sub-district and classified into six classes based on modified-Cookson & Trajstman (2002) as presented in Table 1.

Table 1. Classification of Subterranean Termite Infestation Frequency

No.	Frequency	Description
1.	0	No attack
2.	1-10	Very low
3.	11-20	Low
4.	21-30	Intermediate
5.	31-40	High
6.	> 40	Very High

J. Weight Loss

Weight loss (WL) is the reduction in mass of a test sample after a feeding period, calculated as a percentage of its initial mass. It is determined using the following equation:

$$WL = \frac{W1 - W2}{W1} 100 \quad \text{....(4)}$$

Description:
WL: Weight Loss (%)
W1: Weight of air-dried wood before feeding (g)
W2: Weight of air-dried wood after feeding (g

K. Percentage of Damage

Damage to a bait wood is the ratio between the length of the tested sample's damaged cross-section due to subterranean termite infestation and the initial width or thickness of the bait wood, expressed as a percentage. According to the American Society for Testing and Materials (2006), this damage is classified into seven categories, ranging from no attack to cross-sectional damage greater than 75%.

L. Value of Damage

The value of damage was then determined through a visual assessment of the percentage of the cross-sectional area consumed by termites. This estimation was performed at the point of the most severe termite attack on each sample. To ensure consistency across all samples, the assessment was conducted by the same technician using a transparent grid overlay to aid in quantifying the damaged area. Based on the estimated percentage of wood loss, each sample was assigned a rating from 10 (no attack) to 0 (>75% damage), corresponding to the ASTM D3345-06 standard (Table 2).

Table 2. Classification of damage value sample test against subterranean termite

Value	Damage Percentage
10	No Attack, 1-2% minor damage allowed
9	Penetration reached 3% of the cross-section
8	Penetration 4-10% of the cross-section
7	Penetration 11-30% of the cross-section
6	Penetration 31-50% of the cross-section
4	Penetration 51-75% of the cross-section
0	Penetration >75% of the cross-section

To assess the damage, all bait wood samples were transported from the field sites to the TPMK of the Faculty of Forestry and Environment, IPB University. In the laboratory, each sample was carefully brushed clean of soil, debris, and any attached termite galleries to reveal the wood surface.

III. RESULT AND DISCUSSION

A. Soil Characteristic

The results showed that soil pH in the 12 sub-districts in Bogor City ranged from 5.15 to 7.82. This value indicated that soil pH was not a limiting factor in subterranean termite infestation activity. This is supported by the findings of Arif et al. (2020), whose research found that soil pH in Makassar City ranged from 6.03-8.84. In fact, termites affect soil pH and nitrogen and phosphorus content (Tilahun et al., 2021). This result is in line with the research of Indrayani et al. (2021), who stated that termites significantly impact the chemical composition of soil and can increase land productivity. Additionally, their actions raise the pH, potassium, C-organic content, total Nitrogen, accessible Phosphorous, and Cation Exchange Capacity of the soil by more than 100% (Kathbaruah et al., 2024).

The results showed that the C-organic content of Bogor City ranged from 0.6%-6.51%. This value is higher than the research of Arinana et al. (2019) in DKI Jakarta and Subekti et al. (2018) in Semarang, where the C-organic content found in DKI Jakarta ranged from 1.32%-2.51% while in Semarang it ranged from 0.83%-3.18%. Termites are one of the groups of organisms that play a vital role in the decomposition process of organic materials derived from plants. Termite activity significantly influences the chemical properties of soils, including nutrient availability. Enagbonma & Babalola (2020) reported that soils in and around termite mound are enriched in essential nutrients such as potassium, magnesium, and phosphorus, in addition to increased organic carbon content. Termite densities and specific chemical properties of the soil are correlated, indicating microorganisms' significant functions in accumulating soil nutrients (Musbau & Ayinde, 2021). Thus, the presence of subterranean termites can help plants provide the nutrients they need.

Table 3 presents the complete results of the soil characteristics for Bogor City, including soil pH, C-organic content, and soil texture. The soil texture which is the relative ratio of sand, silt, and clay fractions classified using the soil texture triangle. The test results showed that most of the soil texture in Bogor City is clay (found in 9 sub-districts), followed by clay loam (1 sub-district), sandy clay loam (1 sub-district), and one sub-district could not be identified because the C-organic content is above 5%, which was 6.51%. This research showed that the soil texture in Bogor City has an average clay content (43%- 66%), so the soil texture of Bogor City is categorized as clay. According to Lee and Wood (1971), termites dislike sandy soil and choose soil types that contain much clay. This is supported by research by Arinana et al. (2019) in DKI Jakarta, who found that subterranean termites are found in clay textures. According to Jalaludin et al. (2018), termites that decomposed wood are attracted to clay-textured soil. The preference for clay soils can also present challenges for the control of termites. The binding properties of clay can reduce the bioavailability of termiticides, thereby making it more difficult to manage termite populations in clay-rich environments (Wang et al., 2015). The complete results of soil characteristics (soil pH, C-organic content, and soil texture) can be seen in Table 3.

The research demonstrated that soil characteristics and their relationship to termite diversity are important factors influencing infestation rates in different sub-districts. In Situ Gede, where the soil type is clay loam, the result was a higher diversity of termite species. The termite species identified included *M. insperatus*, *M. gilvus*, and *S. javanicus*, indicating that this specific soil type may foster the proliferation of diverse termite species. This could be attributed to the optimal equilibrium between moisture retention and soil aeration, which is conducive to the survival of multiple termite species.

In contrast, Empang, which had a sandy clay loam soil type, exhibited a markedly lower diversity of termites, with only *M. insperatus* species identified. The sandy clay loam soil is characterized by inferior moisture retention and enhanced drainage compared to clay loam, which may restrict the suitability of the habitat for a greater number of termite species. The scarcity of moisture may render it less appealing to other species that require a more humid environment, such as *M. gilvus* and *S. javanicus*.

Other areas with clay soils showed a moderate diversity of termites, typically with two species present, except for Cikaret. Interestingly, Cikaret, known for its frequent flooding due to irrigation canals and a high concentration of decomposing organic waste, had a predominantly soft clay soil. Only one type of termite was found in this area, suggesting that extreme environmental conditions—such as constant moisture and flooding, may create a hostile environment for a wider variety of species. The high termite attack frequency in Cikaret (56%) may be linked to the presence of soft clay soil, which is favorable for termites but limits the diversity of species that can survive under such fluctuating conditions (Nurhadi et al., 2023; Wardhani & Rufina, 2022).

These findings underscore the pivotal role of soil type in shaping the frequency of termite attacks and the diversity of termite species present. The disparate termite populations observed across these regions are likely the result of variations in soil characteristics, including texture, moisture retention, and aeration. These soil attributes collectively influence the suitability of termite habitats (Subekti et al., 2018). Table 5 presents a comprehensive overview of the attack frequency data across the various sub-districts.

B. Temperature and Humidities Characteristic

The results showed that temperature and humidity in Bogor City are very favorable for

Table 3. Soil Texture in each sub-district in Bogor City

Sub-district	pH	C-organic (%)	Texture 3 Fraction			Soil Texture
			Sand	Silt	Clay	
Situ Gede	6.81	1.93	23	39	38	Clay Loam
Sindang Barang	6.65	0.6	19	16	65	Clay
Pasir Jaya	5.96	2.34	20	14	66	Clay
Batu Tulis	5.15	4.65	22	22	56	Clay
Cikaret	6.3	6.51	-*	-*	-*	-*
Empang	7.55	2.66	55	19	26	Sandy Clay Loam
Katulampa	7.82	1.68	16	28	56	Clay
Kedung Halang	6.48	2.38	11	23	66	Clay
Kebon Kelapa	7.35	3.74	32	25	43	Clay
Tegallega	5.9	0.87	19	19	62	Clay
Sukaresmi	5.56	0.89	28	21	51	Clay
Tanah Sareal	7.42	3.42	24	19	57	Clay

termite development. The highest temperature in the research location was 31.5°C, and the lowest was 25.3°C. Meanwhile, the highest air humidity was 91.9%, and the lowest was 67.6%. Fluctuations in the average daily temperature and humidity can be seen in Figure 1.

According to Mairawita et al. (2022), the optimal temperature and humidity for most termites are 16-35°C and 75-90%, respectively (Subekti et al., 2019). Meanwhile, the research by Arinana et al. (2016c) stated that the average temperature in *Coptotermes curvignathus* termite nests ranged from 29.4-33.8°C. High termite-consuming activity is driven by humidity and temperature within optimal ranges (Woon et al., 2019; Andika et al., 2025). Environmental factors that affect termite development are temperature, humidity, rainfall, and food availability. These factors interact and influence each other. Pratiknyo et al. (2020) state that termites thrive in air temperatures between 15 and 38°C and relative humidity levels between 75 and 90%. Areas with relatively high temperatures and humidity are suitable for developing wood-destroying organisms such as termites (Subekti & Raydityamilanio, 2023).

C. Species Identification of the Subterranean Termites

Figure 2 showed that the whole-body morphology of at least three species of subterranean termites were found in twelve sample sub-districts in Bogor City. The termites found consist of two families, Termitidae and Rhinotermitidae. The three termite species found are *Microtermes insperatus* Kemner, *Macrotermes gilvus* Hagen, and *Schedorhinotermes javanicus* Kemner. Table 4 shows the detailed morphometrics for the soldier caste of each species of termite.

Based on the study's findings, termite species from the Termitidae family were the most dominant compared to those from the Rhinotermitidae family. The two species from the Termitidae family were *M. gilvus* and *M. insperatus*. The Rhinoterrnitidae family was represented by *S. javanicus*.

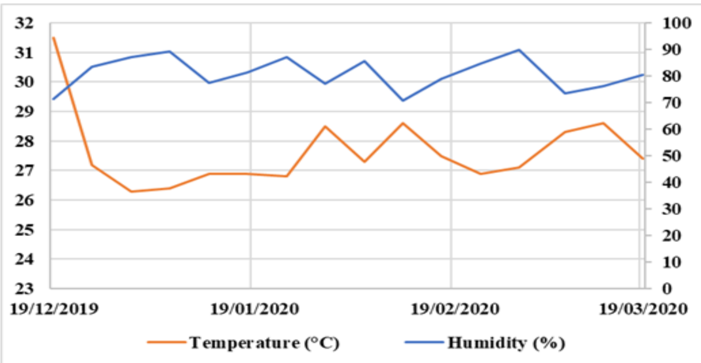

Figure 1. Fluctuation of air temperature and humidity in Bogor City during research

Figure 2. Morphology of subterranean termite species found in the residential area of Bogor City: (a) *Microtermes insperatus* Kemner; (b) *Macrotermes gilvus* Hagen; and (c) *Schedorhinotermes javanicus* Kemner

Table 4. The morphometrics of the soldier caste subterranean termites found in each sub-district in Bogor City

Termite Species	Body part			
	Total body length (mm)	**Head with mandibles, length (mm)**	**Head without mandibles, length (mm)**	**Head, width (mm)**
M. gilvus	8.78±0.73	5.12±0.41	3.95+0.23	2.75±0.2
M. Insperatus	4.34±0.42	1.5±0.08	1.06±0.02	0.91±0.03
S. javanicus	5.41±0.24	2.21±0.16	1.62±0.16	1.29±0.09

The number of termites from the Termitidae family collected from Bogor City's sub-districts was higher, coming to 70 (cumulative of two species), or 86.42%. On the other hand, termites from the Rhinotermitidae family were detected in smaller quantities in the field, a total of 11 (comprising one species) or 13.58% (Table 5). The Termitidae family is often more prevalent than the Rhinotermitidae family. For instance, species such as *Reticulitermes flavipes* a member of the Rhinotermitidae family, are commonly found in temperate regions, but they are often out-competed by higher termites like *Nasutitermes* and *Odontotermes* from the Termitidae family, which are more adaptable to various environmental conditions, including urban settings (Berlanga et al., 2018; Mikaelyan et al., 2014). The family Termitidae is a high-level termite group, representing three-quarters of the total number of termites. While the lower level consists of more families (Rhinotermitidae, Serritermitidae, Kalotermtidae, Archotermopsidae, Hodotermtidae, Stolotermitidae, Kalotermitidae, and Mastotermitidae), and the number in the field is less when compared to the higher level termite groups (Nandika et al., 2015).

Table 5 shows further information about the termites present in each sub-district. The results demonstrated that different termite species were obtained in each sample sub-district. Three termite species were discovered in Situ Gede: *M. insperatus*, *M. gilvus*, and *S. javanicus*. While in Kedung Halang, *M. insperatus*. was discovered simultaneously from eight bait wood.

Table 5. Number of termites found in each village in Bogor City

No	Village	Species	Quantity
1	Situ Gede	*M insperatus*.	5
		S. javanicus.	2
		M. gislvus	1
2	Sindang Barang	*M. insperatus*.	5
		S. javanicus.	2
3	Pasir Jaya	*M. insperatus*.	5
		S. javanicus.	2
		M. gilvus.	1
4	Empang	*M. insperatus*.	1
5	Cikaret	*M. insperatus*.	9
6	Batu Tulis	*M. insperatus*.	3
		S. javanicus.	2
		M. gilvus.	1
7	Katulampa	*M. insperatus*.	3
		M. gilvus.	1
8	Kedung Halang	*M. insperatus*.	8
9	Tegallega	*M. insperatus*.	8
		S. javanicus.	2
10	Kebon Kelapa	*M. insperatus*.	5
11	Tanah Sareal	*M. insperatus*.	5
12	Sukaresmi	*M. insperatus*.	9
		S. javanicus.	1

This study discovered three subterranean termite species that were irregularly dispersed among twelve urban communities. *M. insperatus*. was found in all twelve communities, *S. javanicus* was found in six of them, while *M. gilvus* was observed in four communities. *M. insperatus* is notably the predominant subterranean termite species, as evidenced by its presence in every settlement where bait woods were installed. The results of this study are similar to those of Arinana et al. (2016a), with a research location in South Jakarta, where *M. insperatus* species were found in 76.2% of bait wood. Research on subterranean termite diversity was conducted by Arinana et al. (2016b) in Darmaga Permai I Park, Ciampea, Bogor, and Mubin et al. (2017) on termite diversity at IPB University. The results of the research by Arinana et al. (2016b) stated that subterranean termite species *Macrotermes gilvus*, *Odontotermes javanicus*, *Coptotermes curvignathus*, *Schedorhinotermes javanicus*, and *Schedorhinotermes sarawakensis* were found at the research site, while Mubin et al. (2017) found subterranean termite species *Macrotermes gilvus*, *Microtermes insperatus*, *Odontotermes javanicus*, *Capritermes mohri*, *Schedorhinotermes javanicus* and *Coptotermes curvignathus* at the research site. Research by Arinana et al. (2016b) and Mubin et al. (2017) was conducted in Bogor, but the termites found differed from this recent study. This study did not find *Odontotermes javanicus*, *Capritermes mohri*, and *Coptotermes curvignathus* termite species in the twelve urban sub-districts.

D. Diversity of Subterranean Termites

The richness index (*Ri*) of termite species in the residential area of Bogor City is 0.46. Figure 3 shows the distribution map of subterranean termites. Species richness is the number of species in a community. The greater the number of species found, the greater the richness index. Margalef's richness index, as modified by Arinana et al. (2019), divides the number of species by the natural logarithm function of the amount of bait wood infested by termites. The species richness value of subterranean termites in the residential area of Bogor City is slightly lower than that in East Jakarta and South Jakarta. The research by Arinana et al. (2019) stated that the species richness index in East Jakarta was 0.48, while in South Jakarta, it was 0.51. The value of the species richness index in these three locations is different even though the number of species found in each location is the same, namely three species. This is due to the different amounts of bait wood infested by subterranean termites.

In Bogor City, the amount of bait wood infested by subterranean termites was higher than in East Jakarta and South Jakarta. The diversity index of subterranean termite species in residential areas in Bogor City is 0.62. This is lower than in East Jakarta (0.74) and South Jakarta (0.88) (Arinana et al., 2019). The evolutionary and ecological processes that underlie the difference in termite species richness can be directly impacted by temperature (Pontarp et al., 2019). The diversity index of subterranean termites in Bogor City is lower than in East Jakarta and South Jakarta because the number of bait wood infested by subterranean termites per subterranean termite species is not uniform, which can be seen from the evenness value of subterranean termites in Bogor City of 0.56 which is smaller than in East Jakarta (0.67) and South Jakarta (0.80) (Arinana et al., 2019). Prastyaningsih et al. (2020) found that factors such as soil moisture and canopy cover positively correlate with termite diversity and abundance. In urban area, where these environmental factors may be altered, the resulting changes in termite diversity can lead to shifts in infestation patterns. For instance, a higher diversity of termites may result in a more significant range of feeding behaviors, which can complicate pest management efforts and increase the likelihood of structural damage.

The evenness index shows the degree of evenness in the abundance of individuals among species. The community has a maximum evenness value if each species has the same number of individuals. Conversely, if the evenness value is small, the community contains dominant, sub-dominant, and dominated species. Hence, the community has minimum evenness. The evenness value ranges from 0-1. If the index value obtained is close to one, the distribution is evener. The evenness index of subterranean termites in the residential area of Bogor City also differs from the study of Pratiknyo et al. (2020) in southern Gembong

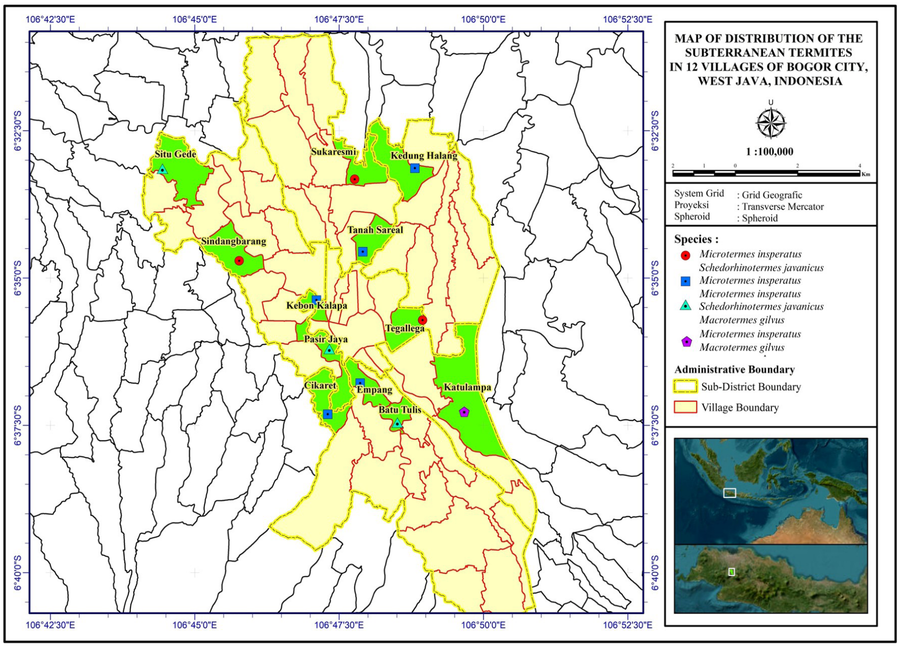

Figure 3. Distribution map of subterranean termites in Bogor City, West Java, Indonesia

(Central Java), where the termite evenness index was 0.73. This indicates that *M. insperatus.* is a dominant termite species in Bogor City. The conversion of land from natural ecosystems to urban has significant implications for the presence and diversity of subterranean termite pests. Land-use changes, particularly forest conversion, resulted in decreased termite diversity, likely due to the loss of suitable habitats and food sources (Liu et al., 2019).

E. Frequency and Distribution of Subterranean Termite Attacks on Wooden Monitors

Table 6 describes the frequency of subterranean termite attacks on wooden monitors installed in 12 urban sub-districts in Bogor City, Indonesia. A total of 300 wooden monitors were installed, with 25 placed in each sub-district. After the three-month exposure period, 48 monitors were unrecoverable, potentially due to environmental conditions or human/animal disturbance, leaving 252 samples for analysis.

Of the 252 remaining monitors, 114 showed signs of subterranean termite attack, such as visible feeding marks and the presence of live termites. Within this group, termites were found to be actively feeding on 81 of the monitors. The overall attack frequency across all sites was calculated to be 38%. According to the classification by Cookson & Trajstman (2002), this frequency is categorized as 'High' (Table 1). This result, however, was notably lower than the 68.5% attack frequency reported by Arinana et al. (2020a) in a nearby residential area.

The frequency of infestation varied significantly between sub-districts. Cikaret sub-district experienced the highest attack rate (56%), while Empang sub-district had the lowest (4%), as detailed in Table 5. The discrepancy in attack frequency could be attributed to various factors, such as different soil types and environmental conditions (Subekti et al., 2018). For instance, Cikaret is an area prone to flooding, which can create softer clay soil conditions favorable to some termite species (Nurhadi et al., 2023; Wardhani & Rufina, 2022). The frequent attacks and the dominance of *M. insperatus.* across these sub-districts indicates their significant role in wood degradation, while the localized presence of *S. javanicus.* in Sindang Barang may contribute to

Table 6. The frequency of subterranean termite infestation of test samples in each urban Sub-district in Bogor City

Village	BW	BWL	WI	WNI	Freq.* (%)
Situ Gede	25	1	11	13	44
Sindang Barang	25	2	13	10	52
Pasir Jaya	25	2	9	14	36
Batu Tulis	25	0	9	16	36
Cikaret	25	3	14	8	56
Empang	25	12	1	12	4
Katulampa	25	3	7	15	28
Kedung Halang	25	10	13	2	52
Kebon Kelapa	25	2	6	17	24
Tegallega	25	7	12	6	48
Sukaresmi	25	6	12	7	48
Tanah Sareal	25	0	7	18	28
Total	300	48	114	138	

variations in damage patterns. These findings emphasize the need for targeted management strategies based on species composition and infestation frequency in each area.

F. Weight Loss

Figure 4 shows the average weight loss of wood eaten by subterranean termites in monitors for 12 sub-districts in Bogor City, Indonesia. According to the results, bait woods from every sub-district had an average weight loss ranging from 5.70% to 29.45%. With a weight loss percentage of 29.45%, Kedung Halang had the most significant weight loss, indicating intense termite activity primarily driven by *M. insperatus*. Meanwhile, the Empang Sub-district recorded the lowest weight loss value, at 5.70%, despite also identifying a case of *M. insperatus*. activity. The single occurrence in Empang suggests that environmental factors, resource availability, or other ecological conditions may limit the impact of termites in this area compared to Kedung Halang. Prior studies in Cibinong, Bogor Regency area, found that weight loss of bait woods was between 9.23% and 22.92% (Nurhadi et al., 2023).

The notable discrepancy in weight loss values across the sub-districts can be attributed to several factors influenced by termite activity. For instance, the elevated level of weight loss observed in Kedung Halang is corroborated by the prevalence of termite infestations, with thirteen recorded attacks in this subdistrict, compared to a single instance in Empang. The presence of *M. insperatus*. is often linked to the availability of wood and other cellulose materials, which serve as food sources. Arinana et al. (2020) found that *M. insperatus*. actively attacked untreated wood samples, indicating their preference for certain types of timber. Termite activity is significantly influenced by local environmental conditions, including soil type, vegetation cover, and the availability of moisture and food sources (Subekti et al., 2018). The clay soil in Kedung Halang, which typically retains more moisture, may provide a more conducive environment for termites compared to the sandy clay loam found in Empang, resulting in elevated termite activity and, consequently, more substantial weight loss.

Another crucial element is the presence of vegetation and human-made structures. In Cikaret, for instance, the number of buildings is less than in Empang. Additionally, open areas are more susceptible to termite activity than densely built-up areas (Mardiansyah et al., 2023; Nurhadi et al., 2023). This indicates that the more open landscape in Kedung Halang may have contributed to the observed elevated termite activity and weight loss, as termites tend to flourish in areas with minimal urban development and greater access to organic matter. *M. insperatus*. was sensitive to changes in their habitat, which can affect their foraging behavior and colony dynamics (Ajayi et al., 2020). Higher soil moisture levels typically enhance their activity, as these conditions facilitate their movement and feeding. Conversely, drought conditions can lead to decreased activity and even colony mortality (Anyango et al., 2020).

The observed variation in weight loss values is reflective of the complex interplay between termite behavior, environmental conditions, and the characteristics of the local landscape. Figure 4 illustrates the total weight loss value for each sub-district.

G. Percentage of Damage

Figure 5 shows the average percentage of damage for each tested site. A one-way ANOVA revealed a statistically significant difference in the percent weight loss among the 12 sub-districts. The average percentage of damage in each sub-district ranged from 1.22±6.09% to 48±50.99% (Figure 5). Kedung Halang showed a score of 71.79% and was the most damaged. Meanwhile, Empang Village saw the lowest proportion of damage, totaling 2.34%. The thirteen termite attacks in Sindang Barang were responsible for the higher value compared to only one assault in Empang. This high level of damage in Sindang Barang can be linked to both the number of attacks and the type of termites present. Termites such as *M. gilvus*. and *S. javanicus*., which are known for their aggressive wood-damaging behavior, were found in higher numbers in areas like Kedung Halang compared to the single species of *M. insperatus*. found in Empang. This aligns with the high termite activity and the presence of *M. insperatus*, these termites are significant pests that require effective management strategies to mitigate their impact (Iqbal et al., 2016). Termites present a dual role in urban ecosystems. While they are crucial for nutrient cycling, their wood-damaging behavior creates a direct conflict with human interests. Addressing the conflict between their beneficial ecological functions and their pest status is a critical consideration for developing effective urban pest management strategies (Anyango et al., 2020).

The damage value percentage in this study, which ranges from 1.22±6.09% to 48±50.99, is

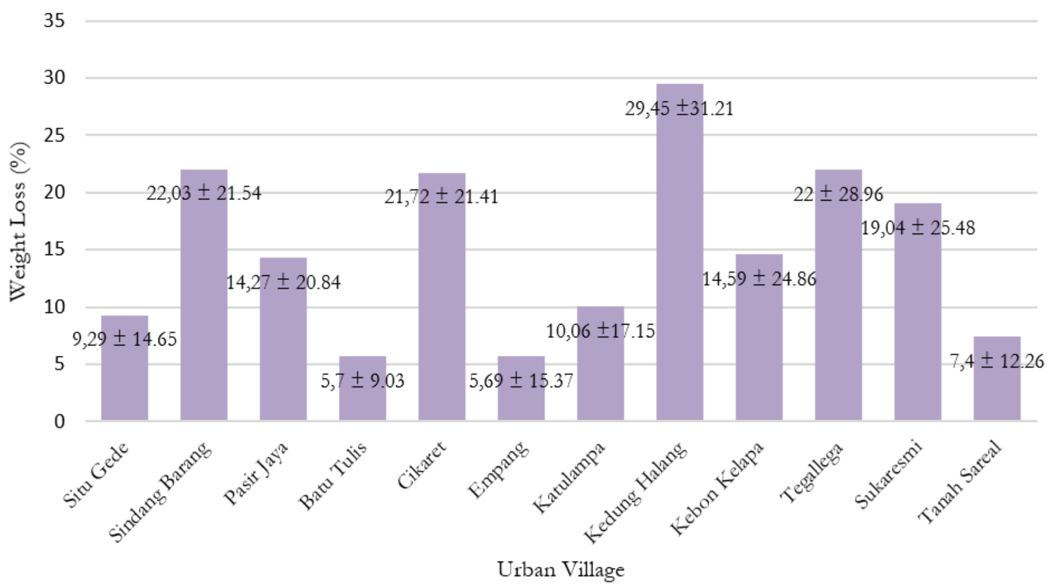

Figure 4. The weight loss +/- the standard error of bait wood in 12 sub-districts, Bogor city

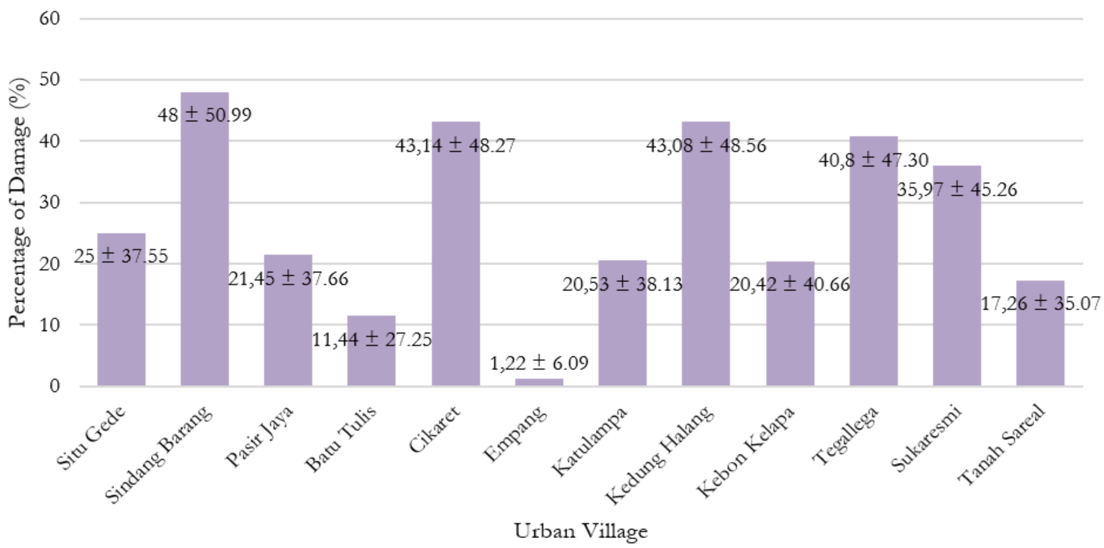

Figure 5. Percentage of damage of bait wood in 12 sub-districts, Bogor city

higher than in the prior study, which was 18,9% in the residential site (Nurhadi et al., 2023). This increased level of damage could result from the unique environmental factors in the site test areas, such as soil moisture and organic matter content, which are crucial in supporting higher termite populations and more severe infestations. Additionally, the frequency of attacks correlates directly with the degree of damage, with more attacks leading to higher damage percentages.

Figure 6. Shows the form of damage to the wood bait in each sub-district. The variation in damage percentages highlights the importance of local environmental and ecological conditions in determining the intensity of termite damage. Soil composition, moisture content, and landscape features all play a role in either mitigating or exacerbating the impact of termite infestations.

H. Damage Value Index

The average damage value of each sub-district ranged from 4 to 9. Empang Sub-district had the highest damage value at 9, while Sindang Barang, Kedung Halang, and Tegallega had the lowest damage value at 4. The higher the damage value that occurs in bait wood, the lower the percentage of damage that occurs in said bait wood, and vice versa. Differences in termite species and location can cause variations in damage value (Fajar et al., 2021).

Table 7 displays the damage values for each sub-district. Each sub-district had a different value of damage to bait wood. Wood consumption by subterranean termites caused weight loss of the bait wood. This was determined by weighing each wood sample before installation and after the three-month exposure period, once cleaned of debris. Subterranean termites consume the whole transverse portion of the bait wood and create transverse holes. Calipers can be used to measure the depth of attack and evaluate the extent of damage to the wood based on eye inspection. Termites' preference for wood is evident in the extent of damage they cause. Moreover, the presence of termites can also affect property values, as potential buyers may be deterred by the risk of infestation and the associated costs of treatment and repair (Gazal et al., 2019). The economic losses attributed to *Reticulitermes* species are significant, with estimates suggesting that termite damage costs homeowners billions of dollars each year (Botch & Houseman, 2018).

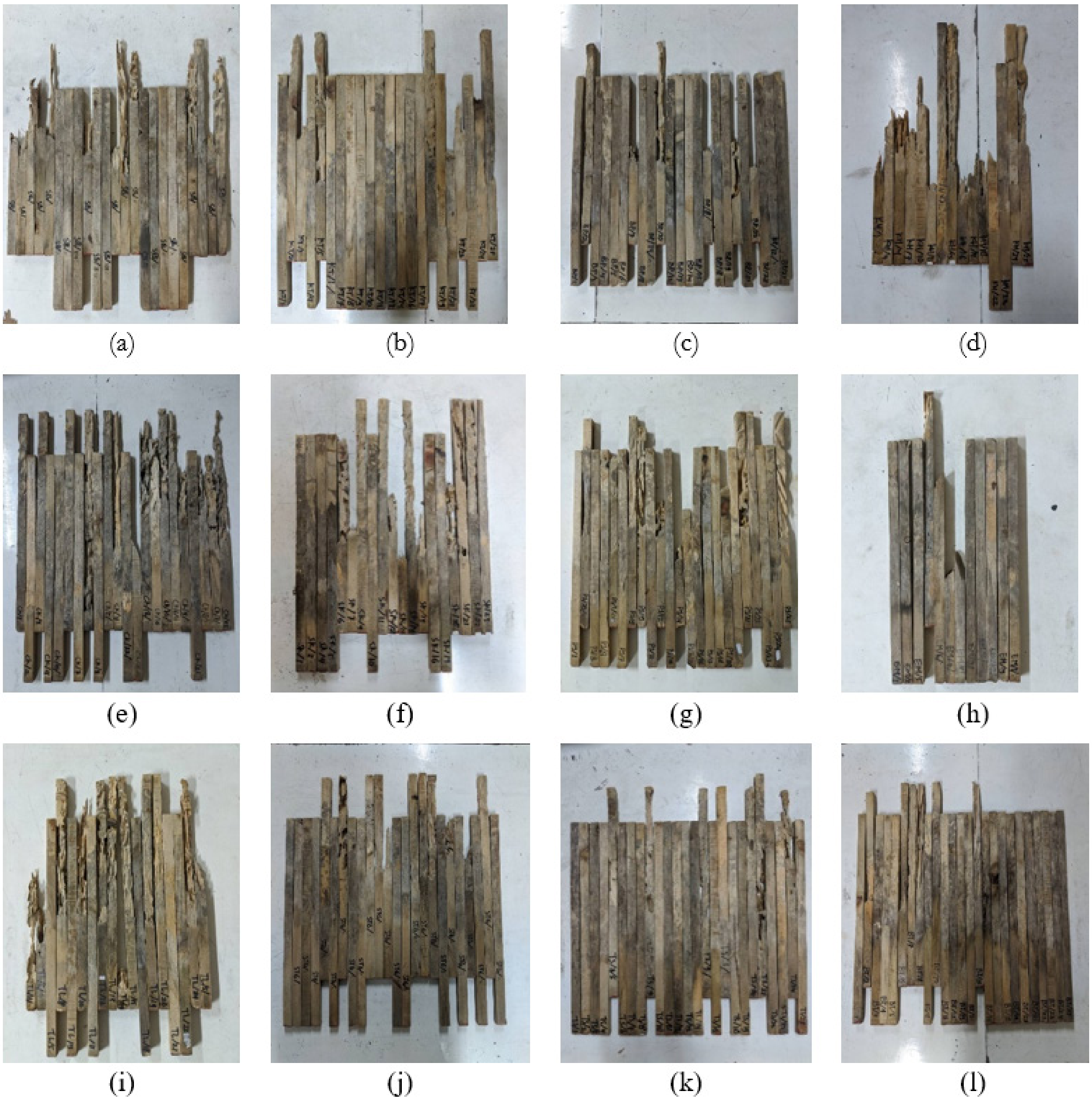

Figure 6. The form of damage to the wood bait in each sub-district, (a) Sindang Barang, (b) Katulampa, (c) Kebon Kelapa, (d) Kedung Halang, (e) Cikaret, (f) Sukaresmi, (g) Pasir Jaya, (h) Empang, (i) Tegallega, (j) Situ Gede, (k) Tanah Sareal, and (l) Batu Tulis

IV. CONCLUSION

The residential area of Bogor City is home to at least three different species of subterranean termites: *M. insperatus*, *M. gilvus*, and *S. javanicus*. The species richness index of 0.46 classifies the species richness as medium, while the diversity index of 0.62 indicates the area's low diversity of subterranean termites. The evenness index of 0.56 shows a medium level of species distribution. *M. insperatus*. is the dominant species found in the urban environment of Bogor City. The presence of termites is strongly influenced by environmental factors such as soil composition, temperature, and humidity, which support their survival in this area. These results provide new insights into the ecological dynamics of termites in urban environments, particularly in densely populated areas like Bogor City.

Table 7. Percentage of Damage in the Cross-section Direction and Value of Damage for Different Sub-district

Villages	Percentage of Damage (%)	Value of Damage*
Situ Gede	26.04	7
Sindang Barang	52.17	4
Pasir Jaya	23.31	7
Batu Tulis	11.44	7
Cikaret	49.01	6
Empang	2.34	9
Katulampa	23.33	7
Kedung Halang	71.79	4
Kebon Kelapa	22.19	7
Tegallega	56.66	4
Sukaresmi	47.32	6
Tanah Sareal	17.26	7

*Based on the ASTM D3345-06 rating scale.

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ASSESSING ZOONOTIC POTENTIAL: A STUDY ON COMMUNITY ACCESS TO NATURAL RESOURCES IN SEBANGAU NATIONAL PARK, INDONESIA

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ASSESSING ZOONOTIC POTENTIAL: A STUDY ON COMMUNITY ACCESS TO NATURAL RESOURCES IN SEBANGAU NATIONAL PARK, INDONESIA. The community surrounding Sebangau National Park (SNP) play a key role in comprehending the epidemiological triad. Peat forests have experienced illegal logging and concessions practises from the early 1970s to 2005. The disturbed forest habitat offers the perfect setting for the inter-species transmission of pathogenic agents. The purpose of this study was to identify any possible zoonotic concerns based on the typical community activities across SNP. Community access data were collected using questionnaires and interview in Kereng Bangkirai (Sebangau River), Asem Kumbang, Baun Bango, Tumbang Ronen, Jahanjang, and Karuing (Katingan River) as the representatives' villages. These settlements are close to the locations used for field sampling (n:102 individuals). The prediction model was developed using CART®Classification for categorical data using MINITAB v. 20.3. We discovered that the model categorised five out of seven factors as important factors. The number of days spent becomes the most crucial predictor (100%), followed by access (95.3%), mode of stay (42.1%), followed by activities (16.8%) and defecation (8.3%), respectively. It was concluded that the longer and deeper they accessed the natural resources; the higher the zoonotic potential would be. The Indonesian Government has established a wildlife health information system, referred to as SehatSatLi, which is designed to protect wildlife genetic resources and reduce the likelihood of zoonotic diseases emerging. It is recommended that stakeholders at all level engaged in coordination, collaboration, and communication as a preventive strategy to inhibit the possible transmission of zoonotic diseases between wildlife and humans, vice versa.

Keywords: Epidemiology, zoonotic, human-wildlife interface, community, classification and regression tree (CART®)

MENILAI POTENSI ZOONOSIS: STUDI TENTANG AKSES MASYARAKAT TERHADAP SUMBER DAYA ALAM DI TAMAN NASIONAL SEBANGAU, INDONESIA. Masyarakat di sekitar Taman Nasional Sebangau (TNS) merupakan kunci di dalam memahami segitiga epidemiologis. Hutan gambut di Sebangau telah mengalami praktik penebangan liar dan konsesi penebangan dari awal 1970-an hingga tahun 2005. Hal tersebut merupakan kondisi yang ideal terhadap transmisi agen patogen antar spesies. Tujuan penelitian adalah untuk mengidentifikasi kemungkinan masalah zoonosis berdasarkan kegiatan masyarakat di beberapa desa yang berbatasan dengan TNS. Data akses masyarakat dikumpulkan menggunakan kuesioner dan wawancara di desa yakni Kereng Bangkirai (Sungai Sebangau), Asem Kumbang, Baun Bango, Tumbang Ronen, Jahanjang, dan Karuing (Sungai Katingan). Permukiman ini dekat dengan lokasi yang digunakan untuk pengambilan sampel lapangan (n:102 individu). Konstruksi model prediksi menggunakan Pohon Klasifikasi Classification and Regression Tree (CART®) untuk data kategorik menggunakan MINITAB v. 20.3 (64-Bit). Hasil menunjukkan bahwa model mengkategorikan lima dari tujuh prediktor sebagai faktor penting. Jumlah hari

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yang dihabiskan menjadi prediktor paling penting (100%), diikuti oleh akses (81,8%), mode menginap (36,3%), aktivitas (15,5%), dan sanitasi (4%) masing-masing. Semakin lama dan jauh akses masyarakat terhadap sumber daya alam; semakin tinggi potensi zoonosisnya. Pemerintah Indonesia telah meluncurkan sistem informasi kesehatan satwa liar, SehatSatLi, sebagai upaya perlindungan terhadap materi genetik satwa liar dan pencegahan terhadap potensi zoonosis yang ditimbulkan. Kami merekomendasikan koordinasi, kolaborasi dan komunikasi dari pelbagai pihak sebagai upaya pencegahan potensi zoonosis dari satwa liar ke manusia dan sebaliknya.

Kata kunci: Epidemiologi, zoonosis, antarmuka manusia-satwaliar, masyarakat, classification and regression tree (CART®)

I. INTRODUCTION

Sebangau Forest experienced logging concessions during the 1970–2000 period. Then, most forest areas were affected by illegal logging until early 2005, before the government took law enforcement actions. Both logging practices have resulted in the loss and fragmentation of Sebangau, one of the strongholds for orangutan habitat in the tropical lowland peat forest ecosystem. The estimated orangutan population in Sebangau (513,500 ha) in 2002–2003 was 6919 individuals (Morrogh-Bernard et al., 2003). Then, in 2014–2015, a population of 5825 individuals in 486,800 ha was discovered using the same nest count technique (Utami-Atmoko et al., 2017). These numbers indicate a population loss of 15.6%.

During illegal logging practices, many canals have been dug. This was a fast and cheap method to transport logs from the forest to the river. However, canals accelerated peat drainage, lost their capability to maintain the water table and became susceptible to forest fires. The estimated 44,607 ha of peatland burned in Sebangau National Park between 2000 and 2012 (RSS GmBH, 2019). Additionally, these canals will become community access points to the forest interior afterward. There are at least three categories regarding high disturbance over the Sebangau peat ecosystem (Husson & Morrogh-Bernard, 2004) which are: 1) forest near the ex-logging camp, through tree removal for camp materials; 2) forest near the settlement and major rivers; related to fast removal of timber species and frequent return visits to log secondary species, and 3) Forest containing a high proportion of commercially valuable individuals; by means that almost every canopy tree is removed and secondary damage is extensive.

The fragmentation of forests has shifted the interactions between intra and inter-species in the area. As a result of being exposed to different factors outside the forest fragment, and due to the edge effects (Fagan et al., 1999; Foley et al., 2005; Murcia, 1995), the orangutan is easily exposed to the transmission of intestinal parasites from humans and other species, and vice-versa. The disturbed forest habitat provides ideal conditions for inter-species intestinal parasite transmission (Gillespie et al., 2005; Gillespie & Chapman, 2008; Martínez-Mota et al., 2017; Mul et al., 2007). Aside from logging and forest fires, little is known about the impact on community activity and access to natural resources for both orangutans and humans, and vice versa, especially for inter-species infectious diseases and parasite transmission, termed zoonotic diseases.

Research has revealed that logging activities have created a patchy mosaic, leading to the so-called compression effect(Cheyne et al., 2018; Husson & Morrogh-Bernard, 2004). These are ideal conditions for inter-species parasite transmission(Gillespie et al., 2008; Mul et al., 2007). Sources of parasite transmission in great apes were tourists, researchers, and the local community (Woodford et al., 2002), and orangutan releases (Kilbourn et al., 2003). The impact of transmission of intestinal parasites from humans to one of the great apes, Chimpanzee populations (*Pan troglodytes ellioti*) was found in Western Cameroon and Nigeria (Fotang et al., 2021). Another studies(Gómez et al., 2013; Medkour et al., 2021) reported the spread of intestinal parasites to humans by populations of gorillas (*Gorilla gorilla*), chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*). This showcases on how the pathogen transmission are reciprocal, especially among great apes.

So far there have been no reported deaths of orangutans in their natural habitat. However, at Orangutan Rehabilitation Centre Bahorok, North Sumaterera, studies have reported eight orangutan death cases. The infections were caused by the parasite *Mammomonogamus* spp. (Foitová et al., 2008; Lowenstine et al., 2018). Protozoa (such as *Entamoeba*, *Endolimax*, *Iodamoeba*, *Balantidium*, and *Giardia*) and nematodes (such as *Strongyloides*, *Trichuris*, *Ascaris*, *Enterobius*, *Trichostrongylus*, and hookworms) have been found in free-ranging and semi-captive Bornean orangutans(Labes et al., 2010; Nurcahyo et al., 2017; Philippa & Dench, 2018). Hence, we focus on examining zoonotic potentials through various human activities, their implications and recommendations towards biodiversity conservation in Sebangau National Park.

II. MATERIAL AND METHOD

A. Study Site/Location

A socio-questionnaire community access data collection method was used in Kereng Bangkirai (KB) the north-eastern part of the Sebangau National Park (SNP), the only adjacent village in Sebangau River. The representatives for Katingan River are Asem Kumbang (AK), Baun Bango (BB), Tumbang Ronen (TR), Jahanjang (JHJ) and Baun Bango (BB), lying in the western part of the park (Figure 1).

There were two considerations in determining villages' choices. First, Kereng Bangkirai is the only village neighboring ex. Setia Alam Jaya logging concession company is now known as the Natural Peat Laboratory, Centre for Information and Management of Tropical Peatland (CIMTROP). Other remaining villages are adjacent to the Punggualas, the representatives of the logged-over forest, hit by illegal logging. The Sebangau National Park (SNP) has appointed this area as one of the eco-tourism sites, observing wildlife becoming the main attraction. Both areas are active orangutan and other wildlife study sites (Utami-Atmoko et al., 2017).

Since many of the communities surrounding the SNP have been involved in illegal logging practices in the past, we are aware that the populations are considered a hidden population. As a result, we used respondent-driven sampling (RDS), which is a type of non-probability sampling approach (Heckathorn, 1997; McCreesh et al., 2013). It begins with a convenience sample of initial subjects, determined accidentally within each village. A free prior consent is signed if the subject agrees to be involved. Otherwise, there are no further discussion. Persons who agree will refer to another subject within their network. This means that not all the subjects are recommended to other persons not involved in specific activities.

A total of 102 individuals, who came from various occupations agreed to fill out the questionnaire. They are willing to share their daily activity and, with no hesitation, respond to any questions. With some adjustment, we used inclusion and exclusion criteria(Panda & Gunawan, 2018) regarding the study objectives. The inclusion criteria are as follows:

1. Person originated from the above-mentioned village and specifically willing to show the ID; notes: the persons are able to recall their experiences during logging activities (between 2000 and 2005)
2. Person actively conducts their activities in and out of the traditional zone of the SNP National Park. For this, the age range should be between 19 and 70 years old.
3. A Person can speak and write Bahasa; speaking in Dayak or Banjar Language is not an issue for those who cannot.

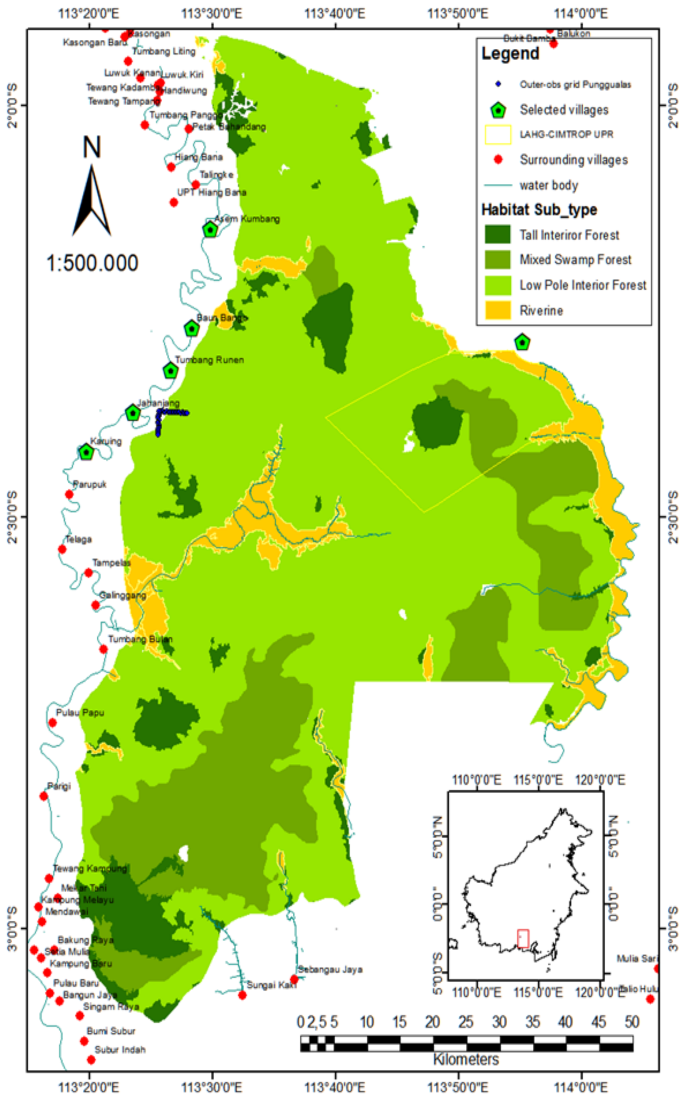

Figure 1. Map of the study area in targeted villages adjacent to Sebangau National Park.

4. Person willing to sign the Free Prior and Inform Consent (FPIC) form.

As for exclusion criteria, the participants are:

1. Not holding any positions in their villages, such as structural organization in the village office (so-called Perangkat Desa or Badan Perwakilan Desa – BPD)
2. Not a civil servant (Teacher, Nurses, Police, and Army).

B. Methods

The study was conducted from 01 February – May 2022. We used a validated questionnaire(Panda & Gunawan, 2018), with some adjustments, on seven predictors, specifically as follows:

1. collector community activities, BRD: Bird hunt (for sale), FW: collect fire woods, GHR: collect gaharu, GEM: Gemor (Alseodaphne coriocea), JEL: Jelutong (Dyera polyphylla), FISH: fishing, GUI: Tourists Guide, HUN: Hunting, LOG: illegal logging, MED PLAN: medicinal plant and PTRL: Forest Ranger.
2. their access in distance: long; >5 km; med: 1-5 km; short: <1 km;
3. Number of days spent: long: > 3 days, med: 1-3 days, and short: <1 day;

4. mode of stay: flying camp, a roof over the boat, making hut, and other (morning – afternoon);
5. their sanitation mechanism during stayed in the forests: making holes, in the river/ tributaries/canals, and others;
6. encounters with orangutan during activity, yes, no, and occasionally; and
7. mechanism for hindering or confronting the orangutan data: avoid and carry on the activities.

Along with those variables, another four (4) factors for data characteristics were also provided: respondents' villages, ethnicity, religions and age distribution.

C. Analysis

Respondents' characteristics and predictors, were summarized using RStudio 4.2.3, package 'gtsummary' and 'huxtable' library (R Core Team, 2022). Pearson's chi square test (χ2) were applied to categorical data, and Kruskal-Wallis test for continuous data, expressed as p-value. The Bonferroni correction for multiple testing, or adjusted p-value, is expressed as q-value. These statistical tests were used to examine the distribution frequency observed in sample is consistent with normal distribution. Classification and Regression Tree (CART) ® Classification is a predictive modelling module that determines the following: 1) ideal classification tree, 2) relative variable importance, and 3) Receiver Operator Characteristic (ROC) Curve. Seven (7) predictors are included in this analysis. Statistical analyses were performed using Minitab® 20.3.

III. RESULT AND DISCUSSION

A. Result

Respondent characteristics – A total of 102 respondents agreed to participate as information sources. All questionnaires' data have been analysed; thus, below are the results summary. Table 1 describes respondents' characteristics by distance travelled (km) from their villages to the interior forests. The age distribution by their access apparently is not normally distributed (p-value: 0.4). The samples observed did not draw the actual age distribution in real population. However, given activities require physical activity, it reflects the age median ranging from 42 to 44 years by distance travelled.

Table 1 describes the activities that penetrates deeper (> 5 km) into the interior was fishing (32%), collecting gaharu *Gonystylus bancanus* (22%), and tourist guide (20%) out of 50 respondents. Furthermore, other activities such as logging, collecting raw material medicinal plants, gemor (*Alseodaphne coriocea* - raw materials for anti-mosquito products) and jelutong (*Dyera polyyphylla* – raw material for chewing gum) latex were relatively had low percentage (<10%).

As the main activity, we observed that fisheries play a significant role in access and duration. It travels up to > 5 km travel using a small boat, through small tributaries or ex-logging channels, especially in wet seasons, in just one day. While in dry seasons, when water is insufficient to support back andforth travel, many local fishermen have made semi-permanent huts near fishing areas. This

Table 1. Subjects' characteristics among targeted villages per access (distance travelled from village to the interior forest)

Characteristic	Deep (> 5 km); N = 50[1]	Edge (<1 km); N = 28[1]	Mid (1-5 km); N = 24[1]	p-value[2]	q-value[3]
Age	43 (37, 50)	42 (34, 47)	44 (36, 51)	0,4	>0.9
Origins					
Asem Kumbang	11 (22%)	2 (7.1%)	0 (0%)		
Baun Bango	13 (26%)	3 (11%)	2 (8.3%)		
Jahanjang	1 (2.0%)	3 (11%)	4 (17%)		

Table 1. Continued

Characteristic	**Deep (> 5 km); N = 50[1]**	**Edge (<1 km); N = 28[1]**	**Mid (1-5 km); N = 24[1]**	**p-value[2]**	**q-value[3]**
Karuing	11 (22%)	12 (43%)	6 (25%)		
Kereng Bangkirai	10 (20%)	3 (11%)	9 (38%)		
Tumbang Ronen	4 (8.0%)	5 (18%)	3 (12%)		
Activities					
Bird for sale	2 (4.0%)	0 (0%)	0 (0%)		
Firewood	3 (6.0%)	2 (7.1%)	2 (8.3%)		
Fishing	16 (32%)	13 (46%)	8 (33%)		
Gaharu (*Gonystylus bancanus*) collector	11 (22%)	6 (21%)	1 (4.2%)		
Gemor (*Alseodaphne coriocea*) bark collector	2 (4.0%)	0 (0%)	0 (0%)		
Guide	10 (20%)	3 (11%)	5 (21%)		
Hunting	3 (6.0%)	0 (0%)	0 (0%)		
Jelutong (*Dyera polyphylla*) sap collector	0 (0%)	0 (0%)	1 (4.2%)		
Logging	3 (6.0%)	0 (0%)	4 (17%)		
Medicinal plant	0 (0%)	3 (11%)	3 (12%)		
Ranger	0 (0%)	1 (3.6%)	0 (0%)		
No_of days				<0.001	<0.001
Long (>5 days)	24 (48%)	1 (3.6%)	9 (38%)		
Mid (1 – 5 days)	20 (40%)	4 (14%)	3 (12%)		
Short (< 1 day)	6 (12%)	23 (82%)	12 (50%)		
Mode of stay				<0.001	0,006
Flying camp	6 (12%)	4 (14%)	6 (25%)		
Making hut	38 (76%)	9 (32%)	12 (50%)		
roof on boat	2 (4.0%)	5 (18%)	4 (17%)		
others	4 (8.0%)	10 (36%)	2 (8.3%)		
Defecation at				0,015	0,1
(Making) hole	1 (2.0%)	1 (3.6%)	0 (0%)		
River/canals	48 (96%)	22 (79%)	24 (100%)		
others	1 (2.0%)	5 (18%)	0 (0%)		
Encounter w. orangutan				0,067	0,5
Yes	30 (60%)	9 (32%)	11 (46%)		
No	1 (2.0%)	0 (0%)	1 (4.2%)		
Occasional	19 (38%)	19 (68%)	12 (50%)		
Responds				0,5	>0.9
Away	26 (52%)	13 (46%)	9 (38%)		
Keep on	24 (48%)	15 (54%)	15 (62%)		
Potent				<0.001	<0.001
high	50 (100%)	5 (18%)	15 (62%)		
low	0 (0%)	23 (82%)	9 (38%)		

[1]Median (IQR); n (%)
[2]Kruskal-Wallis rank sum test; Pearson's Chi-squared test; Fisher's exact test
[3]Bonferroni correction for multiple testing

was suggested that the sanitation mode was inadequate, by means of defecation in the river or tributaries or logging channels. Table 1 shows most of the defecation in the river/ canals, either in long or short distances travelled.

Quantifying such predictors requires a multivariate approach. This was made possible using classification trees, which have the advantage to runs, either small or big datasets. Classification trees use an iterative algorithm, and select the training and test datasets. The objective is to find the best binary splits to construct the classification trees. As mentioned in the method section, seven (7) predictors are involved in the analysis.

The confusion matrix has revealed that the model can accurately predict proper classification. Moreover, from the model been constructed, false-positive (type I error) was low for both training (4.3%) and test (4.3%) datasets. The model provided further notice: : the count of misclassification in the training (4.3%) and test (4.3%) datasets. The receiver operating characteristic (ROC) curve had supported this claim. As a rule of thumb, the more ROC curve away from the linear line, the more accurate the model was constructed. This means that the sensitivity of the constructed model was adequate. Furthermore, the false-positive rate or likelihood type-I error produced was very low, and given the area under the curve (AOC) was 0.9786 (training) and 0.9491 (test).

For the above classification, a tree was chosen as an optimal tree. An algorithm, iteratively splits nodes based on a confusion matrix (Table 2).

Table 2. The confusion and misclassification matrix for training and test datasets derived from seven predictors involved in the CART® analysis

Actual Class	Count	Predicted class (Training)			Predicted class (Test)		
		low	high	% Correct	low	high	% Correct
low (Event)	32	32	0	100.0	32	0	100.0
high	70	3	67	95.7	3	67	95.7
All	102	35	67	97.1	35	67	97.1

Statistics	Training (%)	Test (%)
True positive rate (sensitivity or power)	100.0	100.0
False positive rate (type I error)	4.3	4.3
False negative rate (type II error)	0.0	0.0
True negative rate (specificity)	95.7	95.7

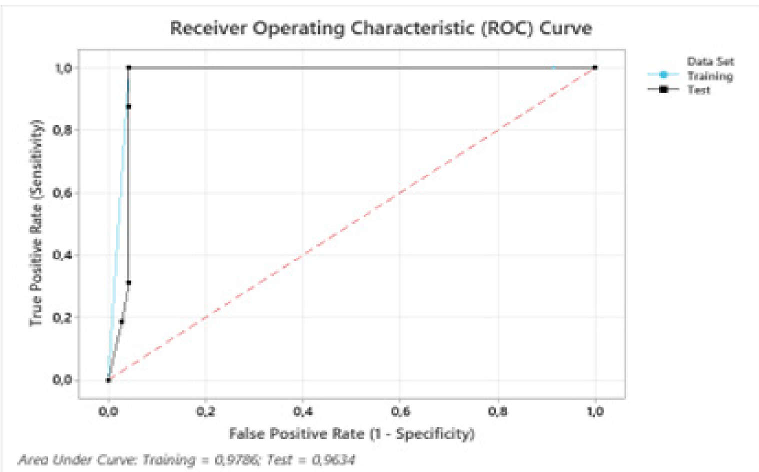

Figure 2. Receiver Operating Characteristic (ROC) curve for training and test data set, on which classification tree model have been constructed

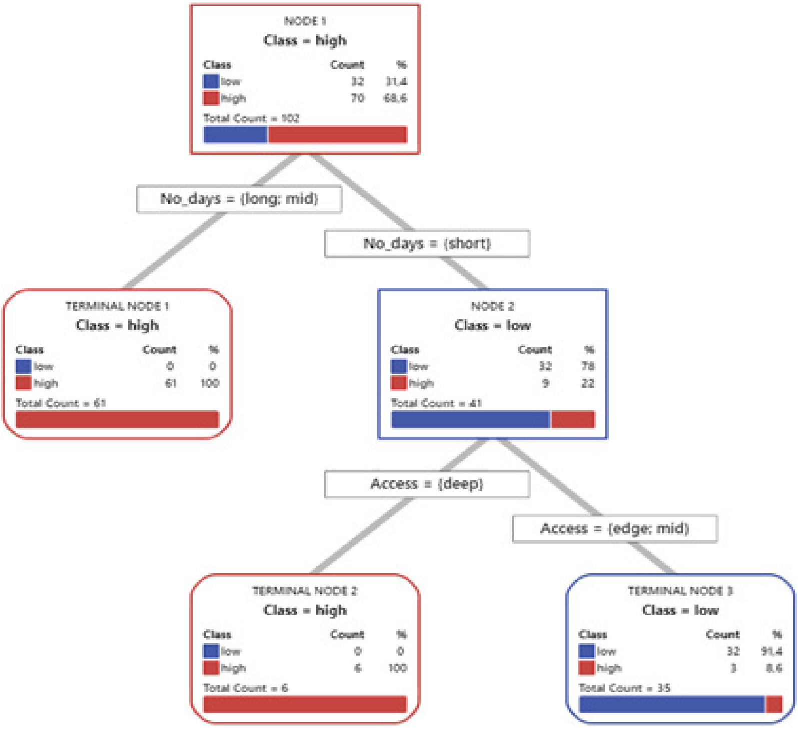

Figure 3. The classification trees indicated the high potential from variable number of days (terminal node 1) and variable access (terminal node2)

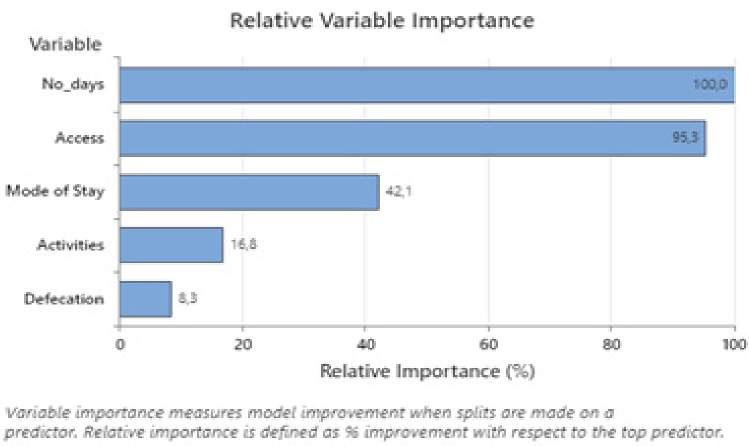

Figure 4. Relative variable importance (RIV) derived from the model

As the most relevant predictor, the variable no of dayswas classified to the right side, whereas long and mid categories (n: 61) were grouped as high. This is turn into a termination node. In contrast, a short day, classified to the left (n: 41), grouped as low. However, as revealed by the confusion matrix, the high event counted for 22%, within the particular node. Access, as a variable chosen by the model, is split to the right side to yield a 100% high event, following the node termination. On other hand, on the left side, the low event has a count (n:32). Again, the high event accounted for 8,6%, on this particular node.

Finally, the model provided the relative variable importance (RIV) which were no of days (100%), access (95.3%), mode of stay (42.1%), followed by activities (16.8%) and defecation (8.3%), respectively. These variables also reflected in Pearson's chi square (p-value:

<0.001), except for the activities and defecation (Table 1).

B. Discussion

Our perspectives construct several arguments for the research findings in the study area. As the main activity throughout the community surrounding Sebangau National Park, fishing plays a significant role in both the protein content of the fish and its economic value. The details of common community fishing practices and the trap equipment's dimensions and mesh size, especially in the Sebangau River, have been reported (Thornton et al., 2018) Several fish trap methods are available; however, the choice must be in line with conservation best practises. The authors imply that the fishing practises are intensive and can be destructive to the fish habitat. The traps used indeed have the advantages regarding the selectivity of fish species, depending on the mesh size. However, the trap placements are not only along the riversides, but also into the interior forest, on which fisherman's hut being constructed near to the fishing areas.

Non-timber forest products, known for their aromatic fragrance, so-called gaharu, were mainly produced by the family Thymelaeaceae, especially *Aquilaria beccariana* van Tiegh and Aquilaria filaria (Oken.) Merr (Giesen, 2015; Paoli et al., 2001; Sitepu et al., 2011). It is harvested from the fungus-infected tree from the *Aquilaria* genus. However, this study has found and witnessed, that villagers (mostly from Karuing) were returning to the forest, collecting gaharu. In contrast, different methods. They brought a 1,20 m long iron stick, and push it down to the peat surface. They were familiar with a particular sound, as the stick hit gaharu beneath the peat surface. Suspected wood, then dig and lifted out of the surface. Returning to the village and weighted at the buyer, and bring the money home. Its aromatic essence was economically in raw materials and crafted as the bracelet and occasionally, a tasbih.


(a)


(b)


(c)


(d)


(e)

Figure 5. The flow-process in pseudo-gaharu starting from collect (a), processing raw-materials (b-d) and a tasbih as one of the final products (e); Source: Anonymous respondent, Karuing Village.

The products are coming from *Gonystylus bancanus* (Miq.) Kurz, of Thymelaeaceae. The wood is expensive and is the most sought-after during logging concessions in the Sebangau ecosystem. Verification has been made for a product claimed as gaharu (Nordahlia & Lim, 2017) and they concluded a product other than the plant genus *Aquilaria*, is called *pseudo-gaharu*. Although it has an aromatic, wood mechanical structure is not similar to the actual gaharu tree, *Aquilaria beccariana* van Tiegh and *Aquilaria filaria* (Oken.) Merr.

Pseudo-gaharu collecting activities, contribute to the orangutan ranging pattern, before and after COVID-19 Pandemic. The so-called compression effect has occurred in the orangutan as they are exposed to the disturbance in a portion of their range, e.g., mostly using those parts that have not been logged or so-called mosaic, and begin to use their home range differently. Furthermore, the study result implies that the flooding event during year 2021, followed by the pseudo-gaharu search activities in Punggualas, contributes to this high prevalence of *Ascaris lumbricoides* in all orangutan faecal samples collected from Punggualas forest (Panda et al., 2023) hábitat.

As for hunting, although very little documented in this study, the hunting is still preserved. The villagers were often accompanied by their dogs, the so-called pig-hunting dog. Dayak Ngaju, one of the biggest tribes in Central Kalimantan, termed these activities as "Mandup". The study found that these dogs were at risk with regards to infectious diseases such as Leptospirosis, in the north of Queensland, Australia, and canine-heartworm infection, in the eastern part of Australia (Orr et al., 2020, 2022). On the contrary, the African swine fever was also taken into considerations, as showcase in North Sumatera(Dharmayanti et al., 2021; Primatika et al., 2022) . No study was conducted on Sebangau orangutan regarding such infectious diseases in the Sebangau wildlife.

In the case of birds for sale, especially most of the Columbiformes Order, the pigeons. According to the respondents, the most wanted are the Passeriformes, the songbirds as *Chloropsis sonnerati* and *Terpsiphone paradisi*. There is also little or no study ever conducted on Sebangau Aves regarding such infectious diseases. In case of bird hunting there was strong evidence for zoonotic, Australia cases. The avian metapneumoviruses; AMPV and human metapneumoviruses; HMPV were closely related viruses with a similar genomic organization and cause respiratory tract illnesses in birds and humans. Reviewed has suggested that HMPVs have evolved from AMPVs' (Jesse et al., 2022).

As for encounters with the orangutan and how the responses were given, implies that they just do not want to kill orangutans. They stated that the orangutans are like humans. This was perhaps, true in the Sebangau case. However, the study found that in Kalimantan, the killing was driven by the way villagers saw orangutans as food sources. Others have mentioned that killing is a self-defence mechanism(Davis et al., 2013; Meijaard et al., 2011). This suggested that consumption of bushmeat, especially non-human primates (NHPs) can be fatal. Many infectious diseases, with confirmed/ probable transmission routes e.g., body fluids, bite/ saliva, organ/tissues, faeces/urine, including vector (indirect), have caused an outbreak in the Cameroon-Congo Basin. Such outbreaks as arboviruses, Ebola, monkeypox, HIV 1 &2, anthrax, salmonellosis, and simian foamy viruses (Hay et al., 2013; Wolfe et al., 2001).

The results have provided a reliable classification model of community access to natural resources in Sebangau National Park. Meaning, that the predictors chosen were sufficiently tangible to describe the model. However, based on our findings, we did not want to accuse or extrapolate about any particular group of people. We wish to identify patterns and trends inherent within our dataset concerning various activities in and surround the SNP. We realize that the SNP authority strives to tighten partnerships with communities. This suggested a potentially serious situation for wildlife conservation that requires conscientious effort and urgency to avoid an undesirable outcome from wildlife-associated health (Buttke et al., 2015; Cunningham et al., 2017; Milstein et al., 2020).

Management implication - The government of Republic of Indonesia through the Ministry of Environmental and Forestry has launched wildlife health information system, called **Sehat SatLi**. The information system was developed to further enhance regulation operationalization and the government program priorities to protect the Indonesian wildlife, specifically their genetic resources, as stated in Ministerial regulation such as the **Permenlhk-RI No. P.2/MENLHK/SETJEN/KUM.1/1/2018** and the Konservasi Keanekaragaman Hayati Directorates' strategic planning 2020-2024.

The results indicate that the imperative for enhanced communication and collaborative efforts among diverse institutions must be promptly instituted. This collaborative engagement should encompass not only foresters, ecologists, and conservation biologists, but also extend to veterinary practitioners, microbiologists, professionals in community health and community leaders (Ancrenaz et al., 2018; George et al., 2015; Schurer et al., 2016; Wich et al., 2012). Therefore, more field actions are needed to achieve government targets, such as raising community awareness on zoonotic potential originate from wildlife within the human-wildlife interface, specifically in SNP. Furthermore, One-health approach (Lebov et al., 2017; Mackenzie & Jeggo, 2019; Pieracci et al., 2016; Thompson, 2013) offers an advantage through their university network within National (e.g., Indonesia One-Health University network, INDOHUN) and Regional (e.g., South-East Asia One-Health University Network, SEAOHUN) scales, in bridging the gap and collaboratively comprehending the emerging zoonotic diseases.

IV. CONCLUSION

The longer (> 5 days) and deeper (> 5 km) the community accessed the natural resources in the interior forests, especially for fishing, gaharu collection and as tourist guide, the zoonotic potential is getting higher. A potentially serious situation for wildlife conservation requires collaborative management to avoid undesirable outcomes from wildlife-associated health, one of which is the One-Health approach.

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UNLEASHING THE POTENTIAL OF THE INDONESIAN TIMBER LEGALITY ASSURANCE SYSTEM FOR LEGALITY ASSURANCE, PERFORMANCE, AND GLOBAL COMPETITIVENESS

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UNLEASHING THE POTENTIAL OF THE INDONESIAN TIMBER LEGALITY ASSURANCE SYSTEM FOR LEGALITY ASSURANCE, PERFORMANCE, AND GLOBAL COMPETITIVENESS. Indonesia has responded to the timber certification obligation imposed by importing countries, particularly the European Union, by implementing the Indonesian Timber Legality Assurance System (*Sistem Verifikasi Legalitas Kayu*-SVLK). This study aimed to evaluate the impact of the SVLK policy on the state of the Indonesian forestry industry and the performance of Indonesian wood goods, mostly plywood, in the international market. Secondary data on Indonesian wood product exports, classified under HS Code 4412, were utilized in this investigation. The analysis revealed that comparative advantage (RCA) analysis was used to assess the competitiveness of Indonesian wood products, while panel data analysis was utilized to assess the impact of the SVLK policy on Indonesian wood export performance. The implementation of SVLK enhanced the value of Indonesian plywood exports; however, the increase was still relatively small compared to other major exporting countries. According to the estimation results, the use of SVLK had a positive impact on the Indonesian plywood trade in the international market. However, Indonesia's ability to increase its market share was still critical so that the Indonesian plywood industry could maximize the potential for expansion in demand for plywood.

Keywords: Exports, FLEGT-VPA, Plywood, Indonesian Timber Legality Assurance System

MENGGALI POTENSI KEBIJAKAN SISTEM VERIFIKASI LEGALITAS KAYU UNTUK JAMINAN LEGALITAS, KINERJA, DAN DAYA SAING GLOBAL. Indonesia telah merespon kewajiban sertifikasi kayu yang diberlakukan oleh negara-negara pengimpor, khususnya Uni Eropa, dengan menerapkan kebijakan Sistem Verifikasi Legalitas Kayu (SVLK). Tujuan dari penelitian ini adalah untuk mengevaluasi pengaruh kebijakan SVLK terhadap kondisi industri kehutanan Indonesia dan kinerja produk kayu Indonesia, terutama kayu lapis, di pasar internasional. Data sekunder ekspor produk kayu Indonesia dengan HS Code 4412 digunakan dalam penelitian ini. Analisis yang digunakan adalah: Analisis revealed comparative advantage (RCA) digunakan untuk menilai daya saing produk kayu Indonesia, dan analisis data panel digunakan untuk menilai dampak kebijakan SVLK terhadap kinerja ekspor kayu Indonesia. Penerapan SVLK meningkatkan nilai ekspor kayu lapis Indonesia, namun peningkatan tersebut masih relatif kecil dibandingkan dengan negara-negara pengekspor utama lainnya. Berdasarkan hasil estimasi, penggunaan SVLK berdampak positif terhadap perdagangan kayu lapis Indonesia di pasar internasional. Namun demikian, kemampuan Indonesia untuk meningkatkan pangsa pasarnya masih sangat diperlukan agar industri kayu lapis Indonesia dapat memaksimalkan potensi ekspansi permintaan kayu lapis.

Kata kunci: Ekspor, FLEGT-VPA, Kayu Lapis, Sistem Verifikasi Legalitas Kayu

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I. INTRODUCTION

Indonesia is the world's leading producer of tropical timber (Prasada et al., 2022). Investment in the forestry sector has increased economic output, income, and employment, but limited domestic raw materials, such as logs, hamper export optimization and increase dependence on raw material imports (Sahara et al., 2022). Non-timber forest products (NTFPs) can offer business diversification opportunities in Indonesia to increase exports, primarily by optimizing exports through products such as resins, rattan, and honey (Hazari et al., 2023). Indonesia is ranked third in terms of tropical forest area, trailing only Brazil and the Democratic Republic of the Congo. Indonesia's tropical timber has the potential to benefit the economy. The tropical forests of Indonesia are estimated to cover 109 million hectares (Sari & Widyastutik, 2015). This area provides an opportunity for Indonesia to utilize its forest resources. In 2021, according to data from the International Tropical Timber Organization (ITTO), Indonesia could produce as much as 81,300 thousand m3 of timber (ITTO, 2024). Sumatra is the largest producer of logs in Indonesia, with a production contribution of 67.57% of Indonesia's total log production in 2023, followed by Kalimantan (17.73%) and Java (12.70%) (BPS, 2024). Industrial plantation forests (Hutan Tanaman Industri-HTI), which accounted for 88.45% of Indonesia's total timber production, contributed the majority of the country's timber production (KLHK, 2023). Most forestry products produced by Indonesia are exported as various wood derivatives to countries such as China, Russia, and United States of America (USA).

The export value of Indonesian wood products will reach US$ 4,9 billion in 2021, with a market share of 3% in the international market (Trade Map, 2023). This market niche has positioned Indonesia among the top 10 exporting countries for wood products in the international market. The most popular wood product Indonesia exports to the international market is plywood (Malau et al., 2022). Export contribution reached 43.44% of Indonesia's total processed wood exports in 2023 (Trade Map, 2024). Indonesia also exports several other types of processed wood, but in relatively small quantities compared to plywood, such as chips and particles, pulp, sawn timber, and wood charcoal (Trade Map, 2024). In 2023, Indonesia's plywood exports reached US$ 1,7 millions of all Indonesian exported wood goods internationally. Plywood exports from Indonesia are increasing worldwide (Trade Map, 2024). This demonstrates the enormous potential for Indonesian plywood exports. Demand for plywood in the international market is rising along with Indonesia's plywood exports. This circumstance illustrates the international plywood market's potential for growth.

While conducting international trade in wood products, Indonesia always needs help with various problems. One of them is the issue of illegal logging. This issue has forced Indonesia to ratify importing countries' policies to ensure that Indonesian wood products are produced legally and sustainably. Sustainable forest management is important in supporting high-quality wood production, strengthening Indonesia's position in the global export market (Dwiyanti et al., 2024). This condition is also driven by an increased understanding of environmental issues and the sustainable use of natural resources among consumers. From an environmental standpoint, the current state of the world is quite concerning. Many plant and animal species have vanished from the face of the globe, while others are on the verge of extinction (Klikovac-Katanić & Kosanović, 2012). Therefore, consumers want the products to have exceptional standards, such as eco-labelling on wood commodities (Ekananda, 2017).

One of the eco-labelling policies currently being implemented is the Forest Law Enforcement, Governance and Trade (FLEGT) policy. The FLEGT policy began to develop after the implementation of the Bali Declaration in 2001, a significant international agreement that aimed to address the issue of illegal logging and its impact on global forests. It is hoped that applying this policy would directly protect exporting and importing countries of forest products from crimes and damage that occur in forest areas (Kunkunrat & Hariyadi, 2018). One of the regions that focuses on the implementation of this policy is the European Union. The European Union is very serious about carrying out the results of this declaration by developing various regulations. The European Union, as an importing country for Indonesian wood products, wants to ensure that the wood products used by the European Union are produced from legal forests and sustainable production. In 2003, the European Union launched the FLEGT Action Plan, which oversees two major policies, namely timber policy in the European Union and a timber industry governance agreement called the Forest Law Enforcement, Governance and Trade-Voluntary Partnership Agreement (FLEGT-VPA).

The implementation of this FLEGT-VPA is in the form of a voluntary partnership agreed upon by each country in enforcing laws, governance, and trade standardization instruments (Kunkunrat & Hariyadi, 2018). The primary purpose of this strategy is to improve forestry sector industry governance and provide certainty for timber and wood products imported into the European Union based on partner countries' policies. In addition, FLEGT-VPA has several other objectives, namely regulating the production of sustainable forestry products, improving the economy of communities around the forest (Erbaugh, 2019), fighting illegal logging (Maryudi, 2017) and increasing timber trade (Giurca et al., 2013). In 2009, Indonesia began the process of ratifying the FLEGT-VPA policy with the Indonesian SVLK policy as Indonesia's effort to improve forest governance, reduce illegal logging practices, build a brand image of legal and sustainable Indonesian timber products, and increase the competitiveness of wood industry products in Indonesia (Ekananda, 2017). Unlike FLEGT, SVLK is a mandatory policy for every industry. SVLK implementation in Indonesia involves the Ministry of Environment and Forestry (MoEF) on the upstream side, responsible for overseeing the legality of wood production, and the Ministry of Trade on the downstream side, responsible for regulating the trade of wood products (Suryandari et al., 2017).

The SVLK policy is expected to be a counterbalance in the international trade process. Importing countries' certification obligations, particularly those imposed by the European Union, can have positive and negative consequences. Implementing this policy has positively impacted Indonesian plywood products' competitiveness and market access internationally. However, the implementation of this policy can be classified as one of the non-tariff barriers (Ekananda, 2017; Khaliqi et al., 2018). This study aims to investigate the impacts of the SVLK policy, implemented as a result of the ratification of the FLEGT-VPA policy, on the Indonesian forestry sector and the international market performance of Indonesian wood products, particularly plywood.

II. MATERIAL AND METHOD

A. Types and Sources of Data Study

This analysis relied on secondary data from 2002 to 2021. Data were acquired from various sources, as detailed in Table 1. This study will concentrate on plywood, Indonesia's most significant export commodity in the international market (52%), with HS Code 4412. In Indonesian, wood species used for plywood production include surian (*Toona sinensis*), jabon (*Anthocephalus cadamba*), gmelina (*Gmelina arborea*), manglid (*Manglietia glauca*), rubber wood (*Hevea brasiliensis*), and sengon (*Paraserianthes falcataria*) (Sutrisno et al., 2020). The data used is Indonesian export statistics, with the five leading export destination nations for Indonesian plywood in the international market accounting for 80% of the market, namely Japan, USA, South Korea, Malaysia, and Saudi Arabia. The competitiveness of Indonesian plywood was assessed by comparing its export performance to that of the five major exporting countries for plywood in the worldwide market, namely Canada, China, Germany, and Russia.

B. Method of Data Analysis

Analysis of Revealed Comparative Advantage (RCA)

RCA was employed as an analytical method in this study to examine the competitiveness of Indonesian plywood in the international market. RCA demonstrated the comparative advantage of forestry sector products. Most importantly, RCA demonstrated the competitive advantage of plywood goods by comparing the export value of Indonesian plywood to 5 (five) other plywood exporting countries. Balassa (1977) explains who was responsible for developing RCA. The relative commodity competitiveness index, or RCA, measures a nation's overall standing in the global market for specific goods. The ratio of an exporting nation's market niche to total global exports is called the relative competitive advantage (RCA). Calculating RCA requires utilizing the following formula, which may be seen below (Jamil, 2019; Lindung & Jamil, 2018; Supriana et al., 2022):

$$RCA_{ij} = \frac{x_{ij}/x_i}{X_{wj}/X_w} \quad \text{......(1)}$$

In the current scenario, x_{ij} is the export value of j product in i nation or region; x_i is the entire export volume of all products in i country or area; X_{wj} is the global output of j product; and X_w is the global export value of all products. The RCA index can be interpreted as follows: if the RCA value is greater than 2.5, then the competitiveness of Indonesian plywood is very strong; if the RCA value is between 1.25 and 2.5, then the competitiveness of Indonesian plywood is strong; if the RCA value is between 0.8 and 1.25, then the competitiveness of Indonesian plywood is moderate; and if the RCA value is 0.8, then the competitiveness of Indonesian plywood is non-existent (Wang, 2015).

Analysis of Panel Data

The method of causal analysis known as panel data regression uses both cross-sectional and time series data. A more precise estimation can be obtained using panel data regression analysis (Gujarati, 2011). A panel data regression analysis was utilized from 2002-2021 to investigate the impact of the SVLK policy on the trade of Indonesian plywood on the international market. This market comprised five major export destination nations: Japan, USA, South Korea, Malaysia, and Saudi Arabia. The following is an example of the data panel model that was created:

$$\ln EX_{ijt} = \beta_0 + \beta_1 \ln GDPI_j + \beta_2 \ln POP_j + \beta_3 \ln ER_{ijt} + \beta_4 \ln COT_{ij} + \beta_5 D\_SVLK + \varepsilon \quad \text{......(2)}$$

Table 1. Sources of Research Data

No.	Data	Types of Data	Sources of Data
1.	Indonesian Plywood Export Value	Ratio	UN Comtrade
2.	Importer Country GDP	Ratio	World Bank
3.	Population	Ratio	World Bank
4.	Exchange Rate	Ratio	FX Sauder
5.	Trading Fee	Ratio	UNESCAP
6.	Competitiveness (RCA)	Interval	Processed by authors
7.	SVLK Policy	Nominal	Indonesian Ministry of Environment and Forestry

Where:

EX_{ijt} : Indonesian exports to main importing countries (in millions of US dollars) in natural log (ln)

$GDPI_j$: Importing countries' GDP (millions of US$) in natural log (ln)

POP_j : Importing countries' population (people) in natural log (ln)

ER_{ijt} : The real exchange rate of the exporting countries against the importing country's currency (Rp/LCU) in natural log (ln).

COT_{ij} : Cost on Trade is a cost that must be incurred by importing countries to carry out trading activities between countries (US$) in natural log (ln)

D_SVLK: Dummy SVLK policy implementation (0: Not yet implemented; 1: Already implemented)

β_0 : Constants/ intercepts

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$: Estimated Parameters

ε : Error term

IV. RESULT AND DISCUSSION

A. Result

Indonesian plywood exports to the foreign market grew in value (Figure 1). Indonesia's plywood exports increased in pace with the global demand for plywood. Indonesian plywood exports had a 3% market share in 2021, with a total export value of US$ 4,9 billion. As a result of this good trend, Indonesia's plywood exports presented a chance for the country to expand its market niche in the international market. The obligation to fulfil the SVLK standard for timber products began with the Minister of Forestry's Regulation on standards and guidelines for assessing forest management performance and timber legality verification in 2009.

These provisions require compliance with the standards, criteria, and indicators of sustainable production forestry and timber legality for Timber Utilisation and Industrial permit holders. The regulation applies to large-scale timber harvesting and industrial permit holders, and small-scale or community forestry operations (Astana et al., 2014). As seen after the SVLK policy was implemented in Indonesia (in 2009), the export value of Indonesian plywood continued to experience a relatively significant increase compared to before the implementation of the SVLK policy in Indonesia. This indicates that implementing the SVLK policy can catalyse trade in Indonesian plywood on the international market (Neupane et al., 2019).

Furthermore, the influence of the implementation of the SVLK policy on the plywood trade in Indonesia was examined further by comparing the competitiveness of Indonesian plywood to that of the five central plywood e xporting countries in Indonesia (Figure 2). According to the RCA findings, Indonesia's competitiveness declined from 2002

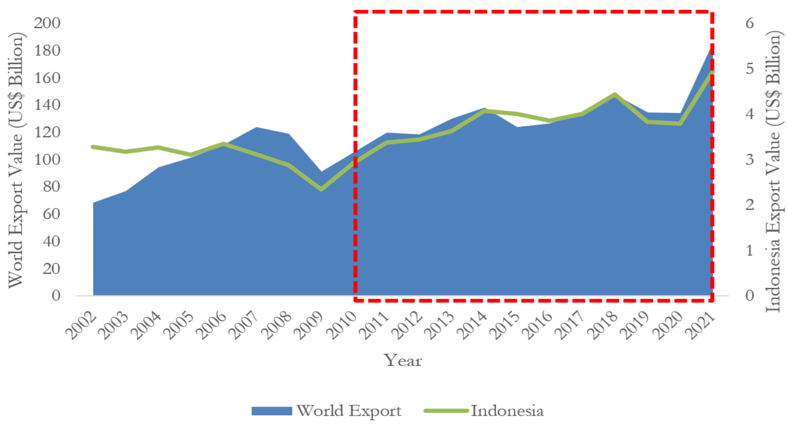

Figure 1. Indonesian Plywood Export in the International Market (Trade Map, 2023)

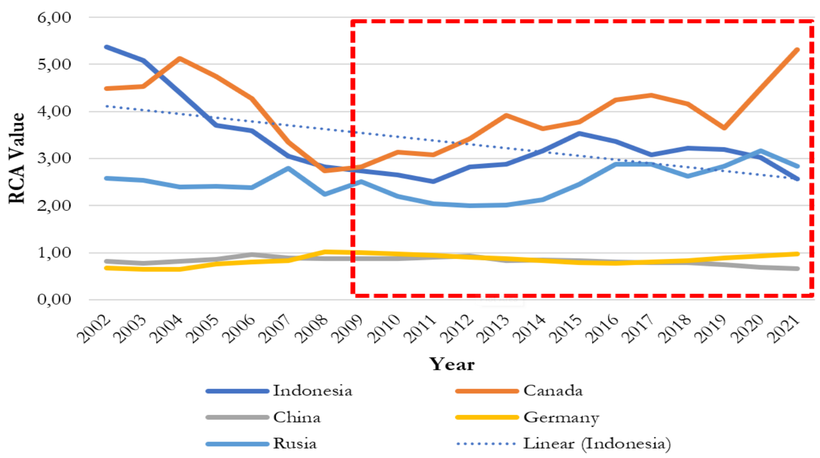

Figure 2. Competitiveness of Indonesian Plywood with Other Main Exporting Countries (Trade Map, 2023)

to 2011. This decrease in competitiveness is due to the increasing attention of global consumers and producers to green products, which encourages the development of environmentally friendly manufacturing. Consumer attention to green products is growing in various countries with programs such as EU-Ecolabel in European Union countries, Environmental Choice in New Zealand, EPA Energy Star in the USA, and EcoMark Africa in Africa (Razif & Persada, 2016). While Indonesia's SVLK policy only began in 2009 due to the slow pace of stakeholders in Indonesia in formulating the timber legality definition, the SVLK policy in Indonesia still needs to be implemented (Prasada et al., 2022). As a result, Indonesian products are considered environmentally unfriendly, and their competitiveness has decreased. On the other hand, Indonesia's exports have also decreased due to the reduction in Indonesia's timber production in the early 2000s (Sari & Widyastutik, 2015).

Establishing Indonesia's SVLK policy in 2009 was expected to boost the competitiveness of Indonesian plywood in the international market. This was not optimally realized since the implementation of the SVLK policy; Indonesian plywood's competitiveness increased until 2015. The competitiveness of Indonesian plywood thus tended to be poor from 2016 to 2021. This scenario suggests that the SVLK strategy has not considerably increased the competitiveness of Indonesian plywood in the international market. Other exporting countries, such as Canada, experienced a favorable trend in competitiveness. A positive trend in a country's competitiveness suggests that the exporting country was able to develop new markets and capitalize on rising demand in international markets.

The reduction in Indonesia's competitiveness was caused by an increase in the price of Indonesian plywood on the international market (Widyastutik & Arianti, 2014). As a result, in the worldwide market, importing countries sought alternative exporting countries for plywood. The rise in the selling price of Indonesian plywood resulted from a policy requiring SVLK for all Indonesian wood products exported. The export price of SVLK-certified processed wood products is 7 % higher than that of similar non-certified products (Aziz & Adrisson, 2020). This assertion is backed by UN Comtrade (2023), as seen in Figure 3.

Impact of SVLK Policy on Indonesian Plywood Trade

The impact of the SVLK policy was assessed using panel data collected from 2002 to 2021. This data included cross-sectional information from Indonesia's five primary export destinations: Japan, USA, South Korea, Malaysia, and Saudi Arabia. During the analysis, various models were evaluated to determine

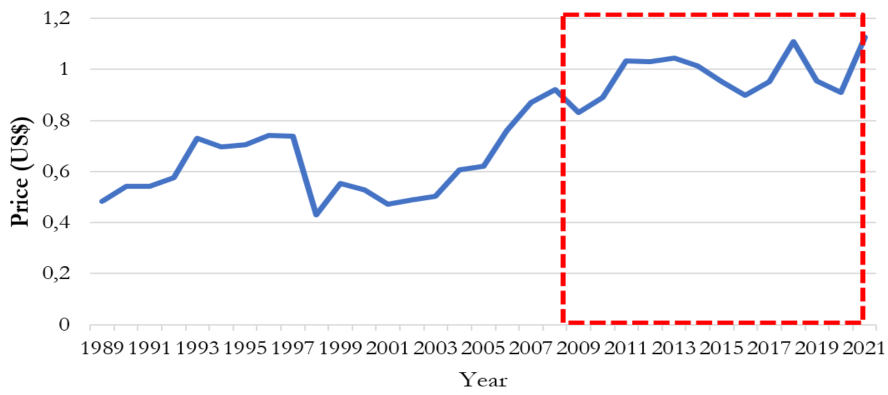

Figure 3. International Market Price of Indonesian Plywood (UN Comtrade, 2023)

Table 2, Estimation Results of the Random Effect Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Ln IMGDP	0.857707	0.064218	13.35627	0.0000*
Ln POP	-0.264880	0.072045	-3.676621	0.0004*
Ln EXRATE	-0.271947	0.041797	-6.506377	0.0000*
Ln COT	1.279000	0.189995	6.731770	0.0000*
DUMMY_SVLK	0.321317	0.132346	2.427852	0.0171*
C	-5.559096	1.920132	-2.895163	0.0047
R-squared	0.806112	Mean dependent var		18.62463
Prob(F-statistic)	0.000000			

Note: Sig. 0.05

the best fit. Specifically, the fixed effects model (FEM), common effects model (CEM), and random effects model (REM) were considered.

The analysis included six variables:

- the value of Indonesian plywood exports to each importing country (EX)
- the GDP of the importing country (IMGDP)
- the population of the importing country (POP)
- the exchange rate (EXRATE)
- the cost of trade (COT)
- a dummy variable for the SVLK policy (DUMMY_SVLK)

To compare the CEM and FEM, the Chow test was employed, resulting in a p-value of 0.000, indicating that the FEM model was superior to the CEM. Additionally, the Hausman test was conducted to compare the FEM with the REM, yielding a p-value of 0.1039. This suggests that the REM was the most appropriate model for the data. Thus, the Random Effects Model estimation was adopted for the analysis in this study.

B. Discussion

Table 2 presents the estimated impact of the SVLK policy on Indonesian plywood commerce. All of the variables investigated in this study can show the effect of the SVLK policy on Indonesian plywood exports to overseas markets. The GDP variable for importing countries describes the economic position of the importing countries. According to estimations, the GDP of the importing countries would have a beneficial impact on Indonesian plywood exports in the international market. According to the parameter coefficient, a 1% increase in the importing country's GDP increases Indonesia's exports by 0.857%. This is because an increase in a country's GDP promotes demand in importing countries (Ardiyanti & Saputri, 2018; Lubis, 2010).

Both the population and the exchange rate harm Indonesian plywood exports on the international market. The population does not significantly affect the demand for plywood exports, despite the decline in furniture production and home construction using plywood, even as the population in importing countries, such as the United States, continues to increase. The demand for plywood in the United States also starts to decrease with an increase in the demand for lumber, veneer, and flooring (Luppold & Bumgardner, 2016). Furthermore, if the value of the Indonesian rupiah increases, the price of Indonesian products will be greater than that of plywood from other exporting countries (Ginting, 2013; Malau et al., 2024; Purba & Magdalena, 2017).

The estimation results, on the other hand, demonstrate that an increase in trade costs will raise the trade value of Indonesian wood products in the international market. According to the estimation criteria, a 1% rise in trading expenses raises the transaction value by 1.29%. This is because Indonesia, one of the world's top timber exporters, has a comparative advantage over other exporting countries. Consumers favor Indonesian wood goods over those from other exporting countries because of the distinctive qualities of Indonesian wood, which comes from tropical forests and is of high quality. Indonesia has been a major source country for plywood products since the 1990s, with the majority of its production originating from the tropics, thereby distinguishing it from products from other countries, such as Taiwan, whose product materials are derived from temperate species (Luppold & Bumgardner, 2016).

The estimation results also revealed that the SVLK policy positively impacted international trade in Indonesian plywood. The estimation results show that the implementation of SVLK will increase exports of Indonesian wood products by 0.321% compared to the absence of SVLK. This suggests that a certification policy would allow the country to increase consumer trust in its products. SVLK legalizes forest products and encourages business actors to conduct reforestation using reforestation funds collected from SVLK fees paid by plywood industry players in Indonesia.

The adoption of SVLK has become a gateway for timber products in Indonesia to access the European Union market. Without the SVLK, wood products entering the European Union market must undergo due diligence regarding their origin (Maryudi, 2017). In general, voluntary certification schemes have implemented the EUTR-required provenance test procedures, including information collection, risk assessment, and hazard prevention (Saunders, 2014; Trishkin et al., 2015).

Following the 2001 Bali Declaration to eliminate illegal logging and indiscriminate processing of forest products, FLEGT-VPA has become a significant EU initiative (Jose, 2021). Even though the terms of an FLEGT-VPA are voluntary but legally binding in perpetuity, Indonesia and the European Union still have a few non-synergistic areas of coordination where market participants are not sufficiently informed (Lung, 2018). Nonetheless, Indonesia and the European Union maintained the reciprocity of their cooperation, as evidenced by the implementation of the Indonesian SVLK, which aims to ensure the administration and legality of imports of forest products, as well as best practices (Jose, 2021).

Certification for forest management is intended to enhance forest management through market-based incentives (Mayers et al., 2002). It is based on evaluating foreign management's social, environmental, and economic elements (Parajuli et al., 2017). It has also been demonstrated that SVLK implementation can increase community participation, transparency, and accountability within the forest management system (Kandel, 2007). Since SVLK was implemented in 2009, Indonesian government regulations governing the legality of wood products have been updated several times. The latest policy is contained in the Regulation of the Minister of Environment and Forestry Number P.30/MenLHK/Setjen/PHPL.3/3/2016 concerning Performance Assessment of Sustainable Production Forest Management and Timber Legality Verification in License Holders, Management Rights, or Forest Rights. In 2020, the SVLK policy was declared invalid by the stipulation of Minister of Trade Regulation Number 15 of 2020 concerning Export Requirements for Forestry Industry Products. Finally, the SVLK policy returned to force after Minister of Trade Regulation Number 45 of 2020 revoked the regulation and restored Indonesia's timber export policy by Permendag No. 84 of 2016 concerning Export Requirements for Forestry Industry Products (Ma'ruf, 2021). The Ministry of Environment and Forestry issued decree no. 1179/MENLHK/PHPL/HPL.3/11/2021 on Determination of SVLK Marks and Decree No. 9895/MenLHK-PHL/BPPHH/HPL.3/12/2022 on Standards and Guidelines for Implementing the Verification and Sustainability System.

V. CONCLUSION

The implementation of the SVLK policy, as part of Indonesia's FLEGT-VPA ratification process, has notably affected the country's primary plywood export within the international market. This policy has contributed to enhancing the value of Indonesian plywood exports, reflecting improved performance in this sector. However, it is important to note that the growth rate of Indonesia's plywood exports has not kept pace with that of other major exporting countries. Consequently, the revealed comparative advantage (RCA) value, which indicates the competitiveness of Indonesian plywood, remained negative following the introduction of this policy, primarily due to rising selling prices in the global market.

Estimates suggest that the SVLK policy has the potential to positively impact the international trade of Indonesian plywood. However, it remains imperative for the Indonesian plywood industry to focus on increasing its market share to leverage its growth potential in plywood demand fully.

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THE VIGOR AND VIABILITY TESTS OF BITTI (*Vitex cofassus* Reinw. ex Blume) SEEDS USING WATER IMMERSION TREATMENT IN A GREENHOUSE

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THE VIGOR AND VIABILITY TESTS OF BITTI (*Vitex cofassus* Reinw. ex Blume) SEEDS USING WATER IMMERSION TREATMENT IN A GREENHOUSE. Bitti (*Vitex cofassus* Reinw. ex Blume) is a group of plants in the Verbenaceae family. The species is classified as a promising endemic plant in South Sulawesi; however, it has received little attention and has not been used and developed optimally. The seed is a recalcitrant category, which has responses to water loss. This study aimed to determine the effect of water temperature and storage periods on the vigor and viability of Bitti seeds. The study was conducted at a greenhouse of the Faculty of Forestry, Hasanuddin University, from May to July 2022. The design of the research was a Completely Randomized Design (CRD) consisting of two factors: water immersion temperature and storage time. Each treatment consists of 30 seeds, with three replications. The results showed that a water immersion temperature of 50°C with a storage period of two weeks gave the best results in the parameters of percentage of sprouts (65,55%), germination viability (65,55%), and mean germinated seeds per day (0,49). The water immersion temperature of 90°C, which was drained for 24 hours without storage, showed the highest value for the mean germination time parameter (31,1), and the soaking temperature of 90°C drained for 24 hours with one week of storage produced gave the best value for the vigor index parameter (4,77). It is considered that germination activities on Bitti seeds require treatment with suitable water immersion. Thus, Bitti seed germination activities require water immersion at a certain temperature and storage time.

Keywords: Bitti, germination, water immersion, storage time

UJI VIGOR DAN VIABILITAS BENIH BITTI (<u>Vitex</u> <u>cofassus</u> Reinw. ex Blume*) MENGGUNAKAN PERLAKUAN PERENDAMAN AIR DI GREENHOUSE FAKULTAS KEHUTANAN UNHAS. Bitti (*<u>Vitex</u> <u>cofassus</u> Reinw. ex Blume*) merupakan pohon yang tumbuh di daerah tropis dan termasuk dalam status kurang diperhatikan (least concern). Benih Bitti bersifat rekalsitran, yang bereaksi terhadap kehilangan air. Penelitian ini bertujuan untuk mengetahui pengaruh suhu perendaman air dan lama penyimpanan terhadap vigor dan viabilitas benih Bitti. Penelitian dilaksanakan di greenhouse Fakultas Kehutanan Universitas Hasanuddin pada bulan Mei-Juli 2022. Rancangan penelitian menggunakan Rancangan Acak Lengkap (RAL) factorial yang terdiri dari dua factor yaitu suhu perendaman air dan lama penyimpanan, menggunakan 30 benih dengan tiga pengulangan. Hasil penelitian menunjukkan bahwa suhu perendaman air 50°C dengan lama penyimpanan dua minggu memberikan hasil terbaik pada parameter persentase kecambah (65,55%), daya kecambah (65,55%) dan rata-rata benih berkecambah per hari (0,49). Adapun suhu perendaman 90°C yang ditiriskan selama 24 jam tanpa penyimpanan menunjukkan nilai tertinggi untuk parameter rata-rata waktu berkecambah 31,1 dan suhu perendaman 90°C yang ditiriskan selama 24 jam dengan penyimpanan satu minggu menghasilkan nilai terbaik pada parameter indeks vigor 4,77. Kegiatan perkecambahan pada biji Bitti memerlukan perlakuan dengan perendaman air yang sesuai. Dengan demikian, kegiatan perkecambahan biji Bitti memerlukan perendaman air pada suhu dan waktu penyimpanan tertentu.*

Kata kunci: Bitti, perkecambahan, perendaman air, lama penyimpanan

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I. INTRODUCTION

Bitti (Vitex cofassus) is a plant in the Verbenaceae family and is classified as a promising endemic plant in South Sulawesi (Melpiany et al., 2020; Muslimin et al., 2020) but has received little attention and has not been used optimally (Adrianto et al., 2015). Nonetheless, Bitti wood has considerable potential to be developed to meet the needs of local and industrial markets (Hayati et al., 2019) because it has strong durability, good texture, flexibility, and resistance to termites (Adrianto et al., 2015). Bitti wood is also included in the class II-III durable wood and strong class II-III (Kementerian LHK, 2020). This wood is used as a raw material for house construction, ship and boat manufacturing, and the furniture industry (Adrianto et al., 2015). In the Solomon Islands, Bitti is used as a raw material for making large drums, and the wood is also one of the primary commodities exported to Japan (Adrianto et al., 2015).

Given the dependence on Bitti wood, which will continue to increase, the demand for the availability of Bitti wood will also be higher in the future. This condition can seriously threaten the availability of Bitti trees in natural forests. Hence, it is necessary to reproduce this species through generative propagation using seeds. Seed of Bitti is classified as recalcitrant (Kurniawan, 2013).

Recalcitrant seeds are a significant challenge in seed storage and conservation (Gayatri et al., 2021), they have a relatively high water content (Bharuth & Naidoo, 2020; Triani, 2021) and are sensitive to water loss (Azarkovich, 2020), making it difficult to store for a long time (Lestari, 2019; Yulianti et al., 2020). This type of seed is sensitive to dry conditions, which may be caused by a lack of sufficient osmotic protection during dehydration (Chandra et al., 2021). These characteristics make it crucial to conserve this type of seed, given the declining number of native species and the associated loss of genetic diversity (Bharuth & Naidoo, 2020).

The long distance from the source of quality seeds to the destination may also cause a decrease in seed quality due to prolong shipping (Batubara et al., 2018). Therefore, seed storage is needed to support the conservation of reciprocal seeds through seed recruitment (Lestari, 2019; Rindyastuti & Siahaan, 2019). Seed storage also aims to provide or preserve planting material (Triani, 2021).

It is also crucial to provide physiological improvement and accelerate the seed germination by doing pre-treatment to get high viability and vigor (Suita, 2019). However, Bitti seed viability is naturally unsatisfactory due to its hard seed coat (Hasnat et al., 2019). The texture of the hard and thick integument makes it difficult for seeds to germinate (Priyono et al., 2021; Rumahorbo et al., 2020).

Germination is a process from seed to shoot in which the plant's metabolic processes are activated after a period of dormancy (Purwanto et al., 2019). Seed germination testing is a method to provide information about a seeds ability to grow (Hartati et al., 2019). According to Paramita et al., (2018) and Triani (2021), quality seeds are influenced by germination. One of the efforts that can be made to accelerate seed germination is to soak the seeds in water (Gea et al., 2018). Seeds will germinate more quickly and produce uniform growth if a proper treatment is applied (Putri et al., 2021).

Many works have been carried out on seed testing of forestry plants of commercial species. However, there is still limited information about Vitex cofassus, research on seed storage, pre-treatment, and vigor testing. The study was to determine the effect of water temperature and periods of storage on the viability and vigor of Bitti (V. cofassus) seed. The findings might be valuable information for other related research..

II. MATERIAL AND METHOD

A. Study Site

The Bitti seeds were obtained from mother trees in Lanna Village, Parangloe District, Gowa Regency, which is a plantation stand with uncertified status, aged between 15 - 20 years. The study activities were conducted at a greenhouse of the Faculty of Forestry, Hasanuddin University, at coordinates of 05º07'38.38" S 119º28'49.03" E. The period of the study was 40 days from May-July 2022. The tools used in this study were machetes, hoes, shovels, sieves, sacks, soil sterilizers, thermometers, germination beds, buckets, a digital camera, SAS 9.4 Portable Software, a set of computers and stationery.

B. Methods

The seeds used were freshly harvested and stored for less than 48 hours after extraction before treatment (W0). The seeds were stored in a refrigerator for the length of storage time according to the predetermined level.

This study was designed using a factorial Completely Randomized Design (CDR) consisting of two factors, namely: 1) water immersion factor (W) consisted of six levels i.e, (W0: No immersion (control), W1: 30°C for 24 hours, W2: 50°C for 3 hours, W3: 70°C for 1 hour, W4: 90°C for 10 minutes and W5: 90°C for 10 minutes drained for 24 hours) and 2) storage periods factor (T) consisted of four levels (T0 : 0 weeks (control), T1: 1 week, T2: 2 wweks and T3: 3 weeks). The treatments were repeated 3 times and each treatment consisted of 30 seeds. The total number of seeds used was 2.160. The linear model used is as follows:.

$$Yger = \mu + \alpha g + \beta e + (\alpha\beta)ge + \varepsilon ger \quad \text{...........(1)}$$

Where :

Yger = observations in the r replication that received treatment with A factor at g level and W factor at e th level

μ = average

αg = influence of A factor at g level

βe = influence of W factor at e level

(αβ)ge = interaction effect of factor A at g level and factor W at e level

εger = error component by A at g level, W factor at e level and r replication or normally distributed random influence (0,σ2).

C. Research Variables

The observed parameters include:

1. The percentage of sprouts calculated using the formula:

$$Germination\ Percentage\ (GP) = \frac{\Sigma sprouted\ seeds}{\Sigma planted\ seeds} \times 100 \quad ..(2)$$

(Surahman et al., 2012).

2. Germination viability was calculated using the formula:

$$Germination\ Viability = \frac{\Sigma normal\ seedlings}{\Sigma germinated\ seeds} \times 100 \quad ..(3)$$

(Husna et al., 2020).

3. Mean germination time was calculated using the formula:

$$MGT = \frac{\Sigma t.n}{\Sigma n} \quad \text{...(4)}$$

Where :

t = days needed to germinate,

n = number of seeds germinated at the end of the observation (Hartmann & Kester, 1983).

4. Mean germinated seeds per day were calculated using the formula:

$$MGD = \frac{N}{t} \quad \text{...(5)}$$

Where :

N = total number of seeds germinated at the end of the observation,

t = number of observation days (Hartmann & Kester, 1983).

5. Vigor index was calculated using the formula:

$$VI = \frac{A1 + A2 + \cdots An}{A1.T1 + A1.T2 + \cdots An.Tn} \times 100 \quad \text{..............(6)}$$

Where :

A = number of seeds germinating on a given day,

T = time corresponding to the number of seeds germinating,

n = number of days in the final calculation (Ayuningtyas et al., 2017).

III. RESULT AND DISCUSSION

RESULTS

A. Analysis of Variance of Two Factors

The results of the seed germination analysis of Bitti can be seen in Table 1. All treatments given to Bitti seeds had a very significant effect on both the unit parameters and their interaction.

B. Percentage of Sprouts and Germination Viability

The interaction between water immersion temperature and storage time on the parameters of percentage of sprout and germination viability can be seen in Figure 1. It shows that the highest treatment values occur at the interaction between 50°C water immersion with two weeks of storage (W2T2).

Table 1. Recapitulation of the germination parameters of Bitti (*V. cofassus* Reinw. Ex Blume) seeds

No.	Observation Parameters	W	T	W*T	Coeff Var (%)	Pr>F
1.	Percentage of Sprouts	**	**	**	18.81	<.0001
2.	Germination Viability	**	**	**	20.07	<.0001
3.	Mean Germination Time	**	**	**	11.35	<.0001
4.	Mean Germinated Seeds per Day	**	**	**	6.80	<.0001
5.	Vigor Index	**	**	**	11.26	<.0001

Note: W = water immersion temperature, T = storage periods, Coeff. Var = coefficient of variation, ** = highly significant effect

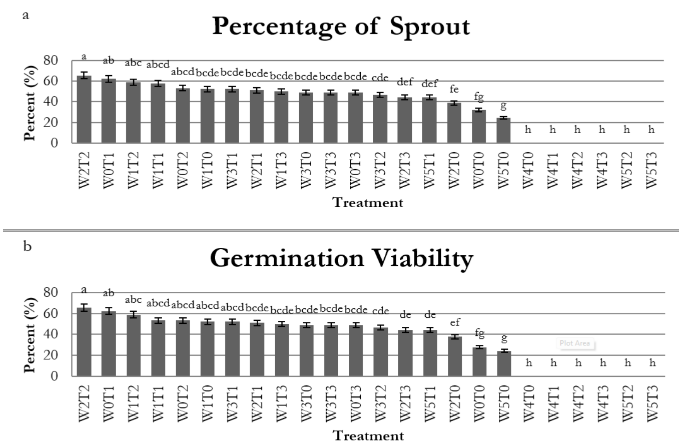

Figure 1. The effect of Water Immersion Temperature (W) and Storage Periods (T) on the Percentage of Sprout (a) and Germination Viability (b) of Bitti seeds. Bars marked with different letters indicate significant differences

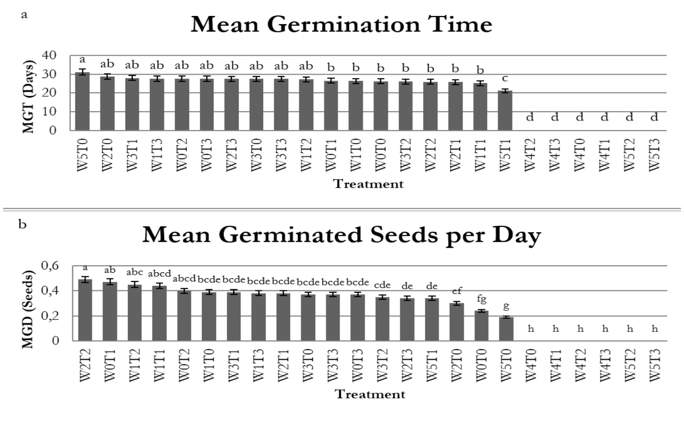

Figure 2. Mean Germination Time (a) and Mean Germination Per Day (b) of Bitti seeds after 40 days of planting, after treatment of water immersion temperature and storage periods. Bars marked with different letters indicate significant differences

C. Mean Germination Time and Mean Germinated Seeds per Day

The highest value of mean germination time is the treatment of temperature at 90ºC, drained for 24 hours, with no storage (W5T0), meanwhile, the mean temperature for germinating seeds per day is 30ºC with a storage period of two weeks (W2T2).

D. Vigor Index

The results of the interaction effect of water immersion temperature and storage length on the vigor index variables can be seen in Figure 3. The seeds soaking in 90°C water, drained for 24 hours, and one week storage (W5T1) gave the best results in Bitti vigor index for 40 days observation.

DISSCUSSION

As stated in the book of Vademekum (Kementerian LHK, 2020) Bitti seeds can be soaked in hot water (90°C) for 10 minutes and then drained for 24 hours. In this study, the interaction treatment of a temperature of 90ºC, drained for 24 hours, and a storage period of one week succeeded in making Bitti seeds germinate on the sixth day. However, the percentage of sprouts was only 6,67, and in the second and third weeks of storage, no shoots emerged in this treatment.

Lower germination rates can occur when the treatment of seeds is too excessive beyond the capacity that the seed can accept. The likely reason is that the immersion temperature of 90°C made the seed coat more permeable, allowing an excessive water intake that exceeded their capacity and resulted in a lack of oxygen, ultimately leading to the seeds demise (Alghofar et al., 2017). It means that the initial temperature of the immersion water should be conditioned due to the possible damage to the embryo (Kusuma et al., 2019).

According to Kurniaty (2010), Bitti seeds can still germinate after three weeks of storage. In the study, the pre-treatment of soaking in water at 90ºC without draining for 24 hours showed no signs of germination. However, seeds were still found to germinate when they were treated with a temperature of 90ºC, drained for 24 hours, and those seeds that had a one-week storage treatment. The treatment without immersion (control) and three weeks of storage, a temperature of 30ºC without storage, and a temperature of 50ºC with two weeks of storage, caused the emergence of early sprouts on the 11th day. From this description, the results obtained in this study were not in line with the results obtained by Kurniawan (2013) that Bitti seeds can germinate on the 29th day after sowing, with a percentage of sprouts of 64,5%. These differences were caused by differences in immersion with different water temperatures to provide further germination responses (Asyi'ah et al., 2019). The difference in immersion temperature, which gives different results, is also possibly due to the ability of each seed to respond to the given temperature shock, as reported by Rumahorbo et al. (2020),

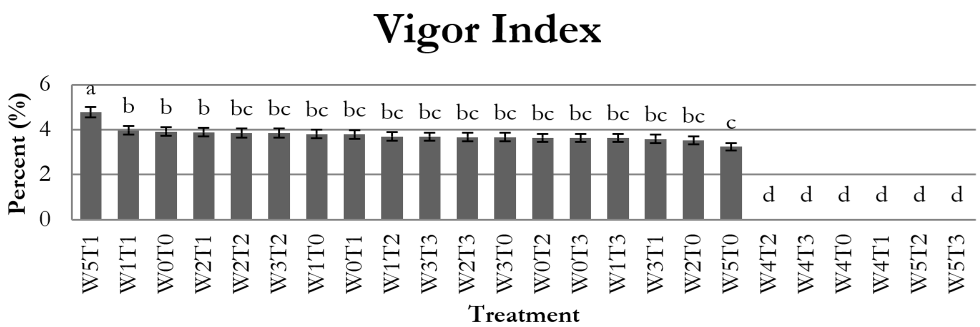

Figure 3. Vigor Index of Bitti seed after 40 days of planting, after treatment of water immersion temperature and storage periods. Bars marked with different letters indicate significant differences

that soaking seeds using hot water can speed up imbibition. This means that differences in temperature will also result in the ability of each seed to imbibe differently.

According to Lemmens et al. (1995), the percentage of early germination of Bitti seeds was between 0-20%, but pre-treatment by soaking in hot water (70ºC) had caused the percentage of germination to increase to 70%, and the seeds began to germinate between 10-40 days. But in this study, the temperature of 70ºC was only able to give a percentage of sprouts of 49,16%, and germination began on the 13th day for treatments without storage and one week of storage, while treatment of two and three weeks of storage resulted germination on the 16th day.

The research conducted by Melpiany et al. (2020) suggested that seeds without soaking treatment are unlikely to absorb water because their skins are difficult to soften and crack, resulting in delayed roots coming out. However, in this study, the control treatment (without immersion) also significantly affected all parameters. Even so, treatment with hot water immersion was still very effective at the germination level (Koobonye et al., 2018; Mamani et al., 2018). This can occur due to environmental factors, as reported by Asyi'ah et al. (2019), that temperature, light, and humidity also help the germination process. In this research, the sunlight received by Bitti sprouts was full, and the humidity of the sprouting media was maintained. The water immersion treatment helps imbibition and activation of maltase, lipase, and protease enzymes (Kurniawan, 2018) and metabolic reaction processes (Rori et al., 2018).

Lestari (2019) and Yadav et al. (2018) stated that the increase in storage periods would cause the rate of germination or seed germination to decrease. This research also found that even with high temperature water immersion treatments, when the storage period was three weeks, the germination did not exceed 50%. Aji et al. (2020) reported that this could happen because of the maturity level of the seeds and the presence of obstacles from the seeds themselves. In this study Bitti seeds used were seeds that had a good and even level of maturity. However, storage periods, especially for recalcitrant seeds, is a key factor in the success and quality of seed germination (Bisht et al., 2021). Long-stored recalcitrant seeds will experience a lack of moisture content during the embryogenesis stage and cell membranes will become damaged (Gayatri et al., 2021; Triani, 2021).

In line with the seed vigor value, Figure 3 shows that the treatment of one week of storage has a higher value than those seeds with no storage. Vitis et al. (2020) reported that long storage resulted in a decrease in seed vigor. The occurrence of a sequence mismatch could be caused when the seeds were taken for germination; the seeds were not selected based on specific standards but were taken randomly, so it was suspected that many seeds from the first week had better properties than seeds that were germinated without storage and vice versa. The effect of other factors in this research might have occurred when differences in immersion temperature were employed.

Appropriate treatment interactions are critical to assessing seed and maintaining high seed viability and vigor (Vitis et al., 2020). Quality and viability are indicators of seeds ability to germinate, produce regular seeds, and describe their germination power (Keti et al., 2022). Seed viability is also described through the maximum growth potential (Wulandari & Farzana, 2020). Meanwhile, high seed vigor is characterized by its long storage resistance, resistance to pest attacks, fast and even growth, and the ability to produce normal mature plants (Keti et al., 2022). The level of seed vigor will reflect the growth strength and growth of sprouts. In other words, the higher the vigor, the better the germination strength (Putri et al., 2021). In addition, seeds that grow quickly and simultaneously can better deal with sub-optimum field conditions, which is part of the value of good seed vigor (Asyi'ah et al., 2019).

One of the aims of seed assessment is to determine the quality level of the germinated seeds by looking at the ability of the seeds to produce sprouts that grow typically or abnormally. Abnormal sprouts are seeds with embryos that have died, and the endosperm is no longer intact due to decay, so the dormant seeds will not break and germinate (Aji et al., 2020). In other cases, especially the seeds that have been treated with 90°C immersion without draining, mold was found in the sand sprout media. It is certainly an indication that the seed can no longer grow. Fungi can cause seeds to rot and become damaged and eventually the seeds will die (Widarawati et al., 2022).

The percentage of sprouts and germination viability are the influential parameters in determining normal and abnormal sprouts. In Figures 1a and 1b, there were no significant differences in the yield parameters of percentage of sprout and germination viability. It is because, during the observation activities, only a few abnormal sprouts were found in each treatment. Based on the data found, odd sprouts were only seen in W1T1 (four abnormal sprouts), W0T0 (four abnormal sprouts), and W2T0 (one abnormal sprout) treatment. The abnormal sprouts did not reach 10% of the total germinated seeds. The cases of abnormal sprouts that were found during the observations were relatively uniform; namely, at the beginning of the appearance of the ovule, they looked normal as usual, but when they entered the age of a few days, there was a fungus infestation around the sprouts. The conditions of moist and closed media cause poor germination and eventually die.

The endosperm of the seed contains high carbohydrates and glucose that provide a good ingredient for fungi growth surrounding the seed. This condition makes the embryo unable to germinate due to the unavailability of energy (Putri et al., 2021). It is also stated that one of the factors that influences the occurrence of abnormal sprouts is the planting medium is too dense and moist. This causes the radicle to bend and the primary root does not grow well. Seed maturity is an essential factor in the germination process. The immature seeds do not have sufficient food reserves, and the imperfect seed structure may inhibit the germination process (Gea et al., 2018) that causing incomplete growth

IV. CONCLUSION

It is concluded that the best treatment to increase the percentage of sprouts, germination viability, and mean germination of seeds per day was the immersion temperature of 50°C after being stored for two weeks (W2T2) under refrigerator storage conditions. The high temperature treatment of 90°C is not recommended because it gives a low sprout rate.

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Water is a necessary part of every reasons's diet and of all the nutrient a body needs to function, it requires more water each daya than any other nutrients a body needs to function, it requires more water each day than any other nutrient (Whitney & Rolfes, 2011)

Or

Whitney and Rolfes (2011) state the body requires many nutrients to function but highlight that water is of greater importance than any other nutrient.

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