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Harvesting Systems of Private Forests in Indonesia: A Review

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Abstract

A private forest is a forest located on land that is burdened with property rights. Harvesting activities in private forests have an important and strategic role in improving the welfare of the Indonesian people, especially in rural areas. Therefore, this research presents a review of harvesting systems used in private forests in Indonesia. This research used a literature review. The research found that various forest harvesting systems are used in private forests in Indonesia. The basic criteria for selecting a harvesting system for private forests were a timber sales system, low equipment costs, labor-intensive, and adaptivity to local conditions. A chainsaw was the cutting tool used for felling, debranching, and bucking. The forest harvesting systems used were manual, modified motorbikes, animals, winches, tractors, and simple skyline systems. These systems followed the characteristics of private forests in Indonesia, such as small diameters and cutting volumes, spread out, and various types of wood. Harvesting of private forests is mainly carried out by small-scale contractors, who are self-taught workers and have not received special training in harvesting techniques, log bucking,wood extraction, and chainsaw maintenance. Improvement of wood extraction techniques is urgently needed, especially in aspects of the modified motorbike operating system.

Keywords: *local adaptive, harvesting technique, harvest decision, operational standard*

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Introduction

Indonesia has several classifications of forest types. According to Law Number 41 of 1999 concerning forestry, forests can be state or private-owned. The total area of Indonesian state forests is 120.3 million ha, consisting of 86.9 million ha with forest cover and 33.4 million ha without forest cover (unforested area). The area of forests that has forest cover consists of 45.3 million ha of primary forest, 37.3 million ha of secondary forest, and 4.3 million ha of plantation forests (MoEF, 2020). In 2020, the area of state forests was approximately 80% of the total area, and the remaining 20% was privately owned (CSBI, 2020). The area of private forest in Indonesia is smaller than in other countries, such as Europe. In European countries, where private forest areas are larger than state-owned. More than half of Europe's forests, excluding Russia and other Commonwealth of Independent States countries, are private (Schmithüsen & Hirsch, 2010). State forests are vast and massive and are generally managed as large-scale businesses by State-Owned Enterprises (SOE) as well as private companies. According to small areas and fragmentation, private forests are managed directly by the forest owner.

State and private forests are expected to be managed sustainably to provide maximum benefits for the welfare of the people (Hardjanto et al., 2012; Djamal et al., 2018; Sukwika et al., 2018). Meanwhile, many parties are involved in achieving SFM in Indonesia and providing forest benefits, both ecologically, economically, and socio-culturally. In particular, sustainable benefits in the form of logs from state forests are aimed at balancing the supply-demand of industrial raw materials, in which forest management is in the form of natural and plantation business units. The achievement of SFM by the natural forest business unit has not been as expected. This can be proven by the various forms of deforestation (Kusmana, 2011) and the inability of the natural forest business to provide logs for wood industries (ANTARA, 2017).

Private forests in Indonesia have unique characteristics. The private forests are small, fragmented, and managed by individual owners (Sanudin & Fauziyah, 2015; Apriyanto et al., 2016; Hardjanto, 2017). The area of private forests owned by farmers in Indonesia is at least 0.25 ha, and the three types are monoculture, mixed forest, and agroforestry systems (Achmad & Purwanto, 2014; Achmad & Diniyati, 2015; Hisma et al., 2015; Olivi et al., 2015; Listiyawan et al., 2022). There are four types of plants developed in private forests, i.e. forestry tree species, multi-purpose tree species (MPTS), estates and agricultural crops (Pratama et al., 2015; Wijaya et al., 2016; Siarudin et al., 2022). Besides, several common non-timber forest products found in private forests are rattan, resin, and nutmeg (Diniyati & Achmad, 2015; Kalima & Sumarhani, 2015; Fauziyah et al., 2015).

Since early 2000, private forests have played an important role in supplying logs and have made a real

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contribution to the welfare of the Indonesian people (Widarti, 2015; Wijaya et al., 2015; Achmad et al., 2015). These forests are expected to become the main source of log production, which increased by 18.6% between 2009 and 2014, as well as from the original 3.2 million m^3 in 2009 to 3.93 million m^3 in 2015. The increase in log production from private forests was higher when compared with log production from natural forests, which was only 4% in the same period. Moreover, the government also targets wood production from private forests at 100 million m^3 $year^{-1}$ (MoEF, 2015). The continuity of the supply chain from private forests is determined by the log production process, especially the felling, wood extraction, and transportation.

The harvesting system for private forests is different from natural forests and industrial plantation forests. The unique characteristics of private forests, such as harvesting needs (locally known as "*tebang butuh*"), the small diameter of the wood harvested in the remote location with the low quality of the road network, the small and scattered area, and the various timber species, influence the selection of the forest harvesting system (Endom et al., 2006; Hinrich et al., 2008; Dalya & Mujetahid, 2019). Furthermore, a low-cost, flexible, safe, and environmentally friendly forest harvesting system is needed for the sustainability of its utilization (Tinambunan, 2008; Tinambunan & Sukadaryati, 2009; Sukadaryati et al., 2021).

This research reviewed the forest harvesting systems in private forest management in Indonesia and evaluated the current conditions, problems, and challenges. It analyzes the characteristics of the private forest management system, equipment, and productivity of the harvesting system. The research provides information and a basis for developing and taking further steps to improve Indonesia's private forest harvesting systems.

Methods

This research uses three stages of literature review. The first stage is a literature search using the *systematic review* method, which refers to the *preferred reporting items for systematic review and meta-analysis* (*PRISMA*) guidelines, consisting of identification, screening, eligibility, and acceptance (Liberati et al., 2009). The identification step is performed by tracing literary sources in cyberspace. A search for articles used various keywords in Indonesian and English. The articles were searched using keywords or search terms "Indonesia private forests (*hutan rakyat*)" or "Indonesia private forest management (*pengelolaan hutan rakyat*)" in tandem with "chainsaw (*gergaji rantai*)", "forest harvesting (*pemanenan hutan*)", "timber harvesting (*pemanenan kayu*)", "wood extraction (*ekstraksi kayu*)", "tree cutting (*pemotongan pohon*)", "tree felling (*penebangan pohon*)", and "wood skidding (*penyaradan kayu*)". Screening is the step of filtering duplicate articles. After eliminating duplicates, a process of literature assessing appropriateness is carried out by extracting information from the title and abstract. Eligible articles are relevant to the aims and questions of this research. The study's research questions are: 1) how are the current practices of timber harvesting in private forests in Indonesia?, and 2) what are the harvesting systems used in private forest management in Indonesia? Meanwhile, literature acceptance is the determination of articles that meet the inclusion criteria and are fit for use in qualitative and quantitative synthesis. The inclusion criteria used in this study were: 1) the research was conducted at private forests in Indonesia; and 2) present information or data on system operation, time consumption, and productivity of harvesting systems in private forests. Acceptability is performed by reading the entire content of the article.

Peer-reviewed journals are obtained from SINTA (https://sinta.kemdikbud.go.id) and GARUDA (https://garuda.kemdikbud.go.id), web-based information systems of Indonesian academics and scientific works. Literature was also collected from other data sources, such as Scopus, Web of Science, Research Gate, Science Direct, and Google Scholar. The second stage of the literature search was conducted using the snowballing method, which traces relevant literature in the bibliography through a systematic review. The third stage was for non-journal scientific articles such as proceedings, theses, and dissertations. The database searched includes all articles published from 1990–2022.

Statistical data were obtained from various relevant administrative databases, and these sources provide information on the characteristics of private forest resources, such as area and distribution, log production, tree species, and forest management systems. This data can be sourced from official documents from the Ministry of Environment and Forestry, the Central Bureau of Statistics, local governments, and the Indonesian Forest Business Association.

In this research, the object of analysis is focused on the 4 largest islands, such as Java, Kalimantan, Sumatra, and Sulawesi, with many private forests. Papua, Maluku, Bali, and Nusa Tenggara were not included as an object of analysis. This is because of limited scientific publications on the harvesting of private forests.

The analysis of the hierarchy of the private forest harvesting system used the proposed approach by Lundbäck et al. (2021). The hierarchy consists of the "harvesting approach", "harvesting method", and "harvesting system". The term harvesting approach refers to whether the forest harvesting is carried out on a ground-based, cable-based, aerial-based, or water-based. The harvesting method refers to the form of wood being harvested at the landing in the forest or on the roadside. The forest harvesting system refers to the combination of machinery, labor, and equipment. Furthermore, the forest harvesting systems are classified based on the level of mechanization. Harvesting systems in this review used the classification of Labelle and Lemmer (2019). The systems are classified as motor-manual (MM), semi-mechanized (SM), or fully-mechanized (FM). Motor-manual operations use chainsaws operated by loggers to perform felling and processing tasks, and then wood is transported to landings with machinery (skidders, forwarders, tractors), human power, or animals. Semi-mechanized systems involve the integration of lower mechanized techniques, such as loggers, with machinery (a single-grip harvester). Fully-mechanized systems exclusively use machines such as single-grip harvesters (felling, delimbing, processing) or feller-bunchers (felling), forwarders, skidders or clambunks for hauling, stroke delimbers for delimbing, slashers for processing, or chippers

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for comminution (Labelle & Lemmer, 2019).

Information and data obtained from the literature and statistical database extraction were then synthesized without meta-analysis or qualitative synthesis (*synthesis without meta-analysis, SWiM*) (Campbell et al., 2020).

Results and Discussion

Based on the combination of keywords used in the literature search, a total of 443 articles were obtained. There were 64 articles that were used for further processing, and the rest (379 articles) were excluded. Furthermore, the articles were filtered by reading the entire text, so that a total of 32 articles were selected. These selected articles were then used as databases in the review of the harvesting system of private forests in Indonesia. Research on harvesting private forests in Indonesia is carried out on four major islands, i,e, Java, Sulawesi, Sumatra, and Kalimantan. Of the 32 selected articles, as many as 38% of the research was conducted on the island of Java, Sulawesi (31%), Sumatra (25%), and Kalimantan (6%). The complete process of article selection is presented in Figure 1.

Indonesian private forest management characteristic

Private forests in Indonesia are managed by individual owners, such as farmers, using different methods with limited capital (Sanudin & Fauziyah, 2015; Apriyanto et al., 2016; Hardjanto, 2017). Since the form of the forests is spread over a narrow area, their management is not carried out in an area but based on tree-by-tree management (Sihombing et al., 2013; Yandi et al., 2019; Hardjanto & Patabang, 2019). Tree management is also conducted according to the abilities of farmers. However, not all are carried out in intensive silvicultural treatment as in Kenya, which includes pruning, lopping, pollarding, coppicing, and thinning (Wanjira & Muriuki, 2020).

The SFM principle of private forests is similar to state forests, with the stages of implementation contained in Law Number 41 of 1999. The limited resource ownership of private forest farmers results in its management involving many parties. Land preparation, forest nursery, planting, harvesting, log processing, timber marketing, and institutional activities are a unified series in private forest management. This activity requires various inputs, methods, parties, and interrelated elements, which is complex, and to understand its management, a system approach is needed. Therefore, the management system of private forests can be divided into production, processing, marketing, and institutional sub-systems (Hardjanto, 2017; Syah et al., 2018; Utama et al., 2019).

The total area of private forests in Indonesia was 2.21 million ha, consisting of 0.78 million ha located in Java, and 1.43 million ha outside Java. In 2014, the total area of private forests was 34.8 million ha, of which 2.7 million ha were located in Java and 32.1 million ha outside Java (Hindra, 2006; Noor, 2014; MoEF, 2015) (Figure 1). In 2004, the largest private forests were located on Java Island, reaching 82.6% of the total area, followed by Sumatra, Sulawesi, Kalimantan, and Papua at 6.5%, 6.2%, 4.3%, and 0.4%. Meanwhile, in 2010, the distribution of these forests changed, with the largest area in Sumatra reaching 42.9%, followed by Java, Sulawesi, Kalimantan, and Papua at 38.7%, 10.4%, 7.3%, and 0.72% (Figure 2). According to MoEF (2015), the number of households managing private forests in Java reached 83.5% of the total number.

Private forests have a large potential and tend to increase log production simultaneously. The increase in log production between 2009 and 2014 was 18.6%, from 3.2 million m^3 in 2009 to 3.93 million m^3 in 2015. Private forests supply 46.9% of national log demand, especially for *sengon*, mahogany, teak, *jabon*, and *sonokeling* (MoEF, 2015).

Private forest wood potential per unit area is relatively small compared to natural and industrial plantation forests, and it is influenced by the tree species, tree diameter, commercial stem length, and tree density. The diameter at the breast height (dbh) of the trees varies from 10–70 cm. The average diameter cut for mahogany forests and pine is 30 cm and 22 cm (Budiningsih et al., 2019). Indonesia's potential for private forests with agroforestry systems can reach 61 m^3 ha^{-1}. Meanwhile, mixed private forests vary from 15.7 to 266 m^3 ha^{-1} (Siadari et al., 2013; Herwanti, 2015), and monocultures vary from 66.4 to 325.3 m^3 ha^{-1} (Soendjoto et al., 2008; Anjarsari et al., 2022).

There are four types of plants developed in private forests, i.e., forestry tree species, multi-purpose tree species (MPTS), estates, and agricultural crops (Yuwono et al., 2015; Wijaya et al., 2016; Siarudin et al., 2022). A total of 25

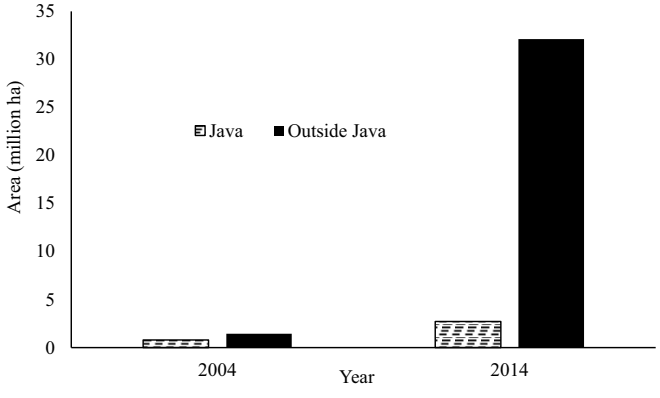

Figure 1 Total Indonesian private forests between Java and others islands in 2004–2014 (million ha).

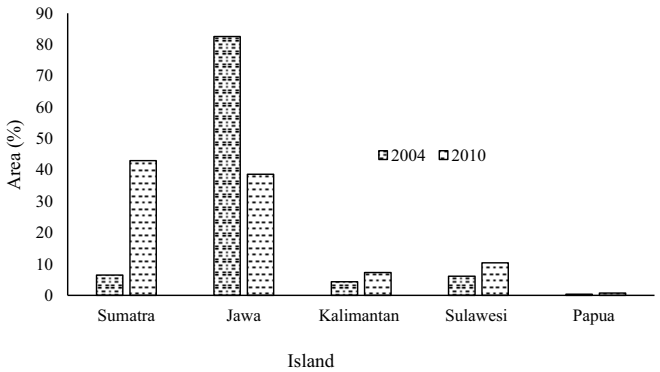

Figure 2 Distribution of private forest areas in the five big islands in Indonesia from 2004–2010.

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forestry tree species are planted. Of the 25 species, 10 species are the most common forestry tree species found in private forests in Indonesia, namely teak (*Tectona grandis*), *sengon* (*Paraserianthes falcataria*), rubber (*Hevea brasiliensis*), *jabon* (*Anthocephalus chinensis*), mahogany (*Swietenia macrophylla*), *mangium* (*Acacia mangium Miller*), *sonokeling* (*Dalbergia latifolia*), *pulai* (*Alstonia scholaris*), pine (*Pinus merkusii*), and *suren* (*Toona sureni*) (Soendjoto et al., 2008; Suryanto & Suryawan, 2015). Besides, several common non-timber forest products found in private forests are rattan, resin, and nutmeg (Diniyati & Achmad, 2015; Kalima & Sumarhani, 2015; Fauziyah et al., 2015).

Logs from private forests are the main source of raw material for the small (traditional) sawmill industry (Syah et al., 2018; Utama et al., 2019). Apart from the sawn industry, the logs of private forests, especially *sengon*, are widely used as raw materials for the bare core industry, plywood, laminated veneer lumber (Budiaman & Komalasari, 2012; Farhan et al., 2019), and furniture (Rahayu & Prihatini, 2009).

The development of private forest management in Indonesia is still facing various problems, either related to economic, social, environmental, or institutional problems. Private forests' contribution to forest farmers' total income is still relatively low (Hardjanto, 2017; Musdi et al., 2020). Furthermore, private forest management has not been able to become the main livelihood of the community (Achmad et al., 2015; Oktalina et al., 2015). Private forests generally have an independent management system determined by each forest farmer (Hardjanto, 2003; Kurniawan et al., 2020). Tree cutting is done according to the farmer's financial needs (Soedomo, 2014; Yandi et al., 2019). There are not many smallholder forest farmers merged in the joint forest management system, so they do not have a high bargaining power when selling timber to buyers. Besides, the forest farmers lack access to the markets to get the right price, especially for timber commodities. The timber supply chain for private forests is still dominated by wood traders who control timber prices for smallholder forest farmers (Sukwika et al., 2018). In terms of environment, scattered private forests cannot provide significant ecological effects on a large scale, but only provide micro-ecological effects. The diversity of vegetation planted in private forest areas causes a low level of erosion hazard (Saputro et al., 2014; Widarti, 2015). Another problem that is often faced by private forest farmers is the government's rules. The establishment of a timber legality assurance system and certificate of timber origin is actually a perverse incentive (Soedomo, 2014; Laraswati et al., 2020).

Hierarchy of forest harvesting system The harvesting method refers to the form of wood being harvested at the landing in the forest or on the roadside. The forest harvesting system refers to the combination of machinery, labor, and equipment (Lundbäck et al., 2021). Based on the approach of Lundbäck et al. (2021), there are ground-based and cable-based approaches to private forest harvesting in Indonesia. Meanwhile, the harvesting method consists of tree length (TL), cut to length (CTL), and sawn timber (ST). In the ST method, sawn timber is piled at the landing or on the side of the haul road. Based on the classification of Labelle and Lemmer (2019), the level of mechanization of forest harvesting systems in private forests in Indonesia is motor-manual (Figure 3).

Harvesting methods There was only one harvesting method in the cable-based approach, i.e. CTL. Meanwhile, in the ground-based approach, there were three harvesting methods, i.e. CTL, TL, and ST. The harvesting method used in private forests with small wood diameters (<50 cm) in Indonesia is the CTL (Gautama, 2008; Dalya et al., 2020). In the CTL method, trees are felled, debranched, trimmed ends, divided into different specific lengths, and transported to the landing point or transport road. The logs' length varies from 1.03–4.00 m (Budiaman & Komalasari, 2012; Sukadaryati et al., 2018). The tree length method is used in private forests that have logs with a diameter >50 cm, and a log length of 21 m (Ghozali et al., 2021). In the TL method, trees are felled, debranched, and trimmed at the first branch, and transported to the landing point or transport road. The TL produces only a commercial stem.

In the ST method, the tree is felled, debranched, and trimmed. The commercial stem is bucked into non-uniform lengths and sawed using a chainsaw at the cutting site to produce sawn timber with various lengths, widths, and thicknesses. The size of sawn timber produced varies depending on the wood species, tree diameter, and market demand. The sawn timber is extracted from the cutting site using a manual system and then loaded into trucks or containers parked on the cutting site. The products from this method are sent to advanced wood industries (Budiaman & Komalasari, 2012; Dalya et al., 2020).

The size of the sawn timber produced is determined by market demand. Budiaman and Komalasari (2012) reported that the specifications from private forests requested by the advanced timber industry were classified into 1) width 13–14

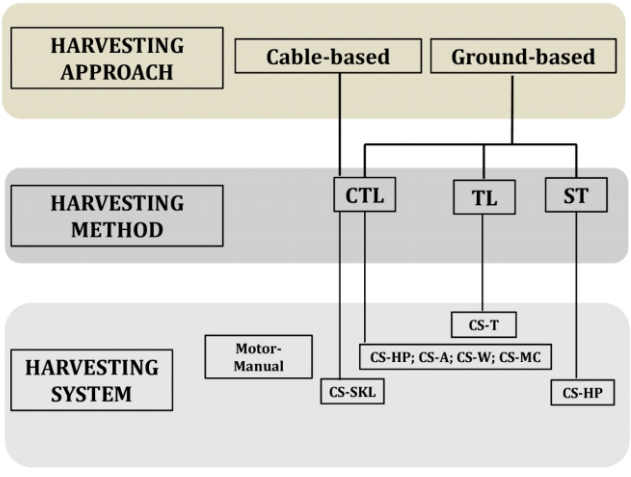

Figure 3 Hierarchy of private forest harvesting systems in Indonesia based on the approach of Lundbäck et al. (2021). Note: CS-T = chainsaw-tractor; CS-HP = chainsaw-human power; CS-A = chainsaw-animal; CS-W = chainsaw-winch; CS-MC = chainsaw-motorcycle; CS-SKL = chainsaw-skyline.

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cm, length >110 cm or length >210; 2) width 15–19 cm, length >110 cm or length >210 cm; and 3) width >20 cm, length >210 cm. Furthermore, the sawn timber produced from the ST method is also intended for direct use, such as building houses. Dalya et al. (2020) reported that the sizes of teak-sawn timber for house construction are 10 cm ×20 cm × 400 cm, 20 cm × 20 cm × 400 cm, and 5 cm × 7 cm × 400 cm.

Harvesting systems The private forests are harvested using a "harvesting for urgent needs" system (locally known as "*tebang butuh*") (Hamdani et al., 2015; Nugroho et al., 2017; Lusiya et al., 2020) by clear-cutting or selective-cutting system. Furthermore, selective cutting is applied in private forests with agroforestry, mixed forests, and monoculture systems, while clear-cutting is only applied in monoculture forests (Wijaya et al., 2015; Risasmoko et al., 2016). Farmers cut their forests when cash is required for urgent needs such as repairing houses, hospital fees, school fees, and holding celebrations (Hardjanto, 2003).

The harvesting operator of the private forest is the private forest owner (farmer), independent harvesting contractor, or harvesting team of wood traders (locally known as "*tengkulak*" and "*pedagang pengumpul*"), the harvesting team of the wood industry. An independent harvesting contractor is a group of people whose special job is cutting and extracting logs in private forests with a wage system. The timber selling system influences the harvesting operators of private forests in Indonesia. There are four timber-selling systems in the private forest business, i.e., stumpage value, number of standing trees, logs assortment, and processed wood (square wood, sawn timber). In the log assortment and processed wood sales system, felling and wood extraction can be carried out by farmers or independent harvesting contractors. Meanwhile, the harvesting team of wood traders and the harvesting team of the wood industry conduct felling and wood extraction in the number of standing trees and stumpage value system. The farmers sell the most timber in the form of stumpage value and a number of standing trees. Only a small proportion of farmers cut their own forests (Endom et al., 2006; Abbas et al., 2021; Purwawangsa et al., 2021).

The technical skills of felling and bucking of harvesting contractors need to be improved. The harvesting contractors do not have an adequate understanding of directional felling techniques and felling cut techniques. The harvesting contractors, especially those outside Java, are generally former illegal loggers in state forests. The independent harvesting contractor in private forests has not been involved in any training related to saw maintenance, felling techniques, and safety forest operations. The harvesting skills of the contractor were acquired through long work experience and self-taught learning (Budiaman & Komalasari, 2012). Parties that have the potential to provide such training are forestry extension workers, research institutions, universities, and non-government organizations. But so far, this has never been done.

The harvesting system in private forests in Indonesia varies according to the region and is influenced by the local community's economic, social, and cultural values. The means of transporting wood used in the private forest with a diameter <50 cm are human power, animals, and skyline. Meanwhile, in private forests that have large diameters (>50 cm), the logs are transported with a winch and tractor. Based on the approach of Lundbäck et al. (2021), there are six proposed harvesting systems in private forest management in Indonesia, namely chainsaw-human power (CS-HP), chainsaw-animals (CS-A), chainsaw-motorcycles (CS-MC), chainsaw-winch (CS-W), chainsaw-skyline (CS-SKL), and chainsaw-tractor (CS-T) (Table 1).

The chainsaw is the main felling tool used in harvesting systems in Indonesian forests, including in private forests (Mujetahid, 2008; Hidayat et al., 2018; Dalya et al., 2020). Several brands include STIHL, Husqvarna, Maestro, East West, New West, Falcon, and Ecolite. It has a capacity of 72–106 cc, an engine power of 3.94.8 kW, and a rotation speed of 2,800–7,500 rpm. The length of the bar used varies from 40–110 cm. A 40 cm bar is used for felling small-diameter trees (<30 cm), while a longer bar is used for large-diameter trees (>30 cm). Mujetahid (2008) reported that the chainsaws' age varies from 2–7 years, with an average of 4.5 years. According to Heru et al. (2009), the average productivity of tree felling in private forests varies depending on the wood species, tree diameter, terrain, chainsaw conditions, and the skill of the felling operator. Of the 32 articles selected, seven articles presented complete data on the productivity of tree felling in private forests in Indonesia. The wood species harvested were *sengon*, teak, *gmelina*, *sonokeling*, *meranti* (*Shorea* spp.), and *kapur* (*Dryobalanops aromatica*). Table 2 presents the average productivity of tree felling for several wood species in private forests.

Chainsaw-human power (*CS-HP*) The CS-HP system uses human power as the wood transporter. This system is used in almost all private forest harvesting due to its low cost, sufficient manpower, and not requiring equipment investment costs. The CS-HP is considered the most suitable harvesting system for rural areas to create jobs for the

Table 1 Harvesting systems of private forests applied in four major islands in Indonesia

Harvesting system	Island			
	Sumatra	Java	Kalimantan	Sulawesi
Chainsaw-human power	√	√	√	√
Chainsaw-animal	-	√	-	√
Chainsaw-motor cycle	√	√	√	√
Chainsaw-tractor			√	
Chainsaw-skyline	-	√	-	-
Chainsaw-winch		√	√	-

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community surrounding private forests, including family members of private forest farmers.

After tree felling and log bucking, the wood is transported on the shoulder or a simple wooden pole. Generally, a felling team consists of 10–12 people. The team consists of one chainsaw man, one helper of a chainsaw man, and 8–10 wood transporters. When shouldered wood transport is used, each worker can carry one or two logs (Figure 4). Meanwhile, by using a simple wooden pole, 2–4 logs can be moved on flat or short, steep terrain. The extraction distance of the manual system varies between 120–150 m. The productivity of the shoulder system is 0.33 $m^3 hour^{-1}$ with an extraction distance of 150 m. When carrying logs with a simple wooden pole, the productivity is 0.45 $m^3 hour^{-1}$ with an extraction distance of 120 m (Endom et al., 2006). Generally, the number of workers involved in the carrying system is 2–4 people. It depends on the size of the logs. The diameter and length of logs determine the number of workers required.

Chainsaw-animal (*CS-A*) Several domesticated animals, such as cows, buffaloes, and horses, are closely related to Indonesian agriculture and culture. Buffaloes and cows are used to plow the fields, while horses and cows propel traditional rural transport. Although originally used only in agricultural work, domestic cows have been used to skid logs in teak plantation harvesting on Java Island. The average productivity of skidding teak with cows is 0.37 $m^3 day^{-1}$ with an extraction distance of <300 m (Tinambunan & Sukadaryati, 2009). Another animal used to skid the logs is the horse, especially in the eastern part of Indonesia (Dalya & Mujetahid, 2019; Abbas et al., 2021).

Chainsaw-motorcycle (*CS-MC*) Motorbikes have been used to transport wood in private forests since the 1990s. According to Basari (2010) and Sukadaryati et al. (2018), modified motorbikes are used in harvesting and designed for use in steep and difficult terrain. The standard gear and tires are replaced with a larger size, and 2–4 shock breakers are installed at the rear part of the motorcycle to improve the suspension system. The modified motorbike is also equipped with a load support device made of wood or iron (Figure 5).

Load supports are installed in front, behind, or on the side, depending on where the logs being transported will be placed. The load supports will be mounted across the motorbike when the logs are placed on the left and right sides of the motorbike. In some places in Java, the transported logs are placed in the space between the saddle and the steering wheel or behind the rider. Transporting logs involves used motorbikes more than 5 years old with an engine capacity of 100–110 cc from various Japanese manufacturers. Special off-road (trail) motorbikes are used in East and West Java areas. The CS-MC system is mostly needed in remote areas, which do not have an adequate forest road network or public roads.

Motorbikes can transport about 5–10 logs per trip with a transport distance of 100–1,000 m. Basari (2010) reported that the average productivity of pine wood extraction using motorbikes is 1.58 m^3 $hour^{-1}$ for every 100 m transport distance. According to Sukadaryati et al. (2018), the average productivity of transporting *gmelina* (*Gmelina arborea*) logs is 0.85 $m^3 hour^{-1}$ with a distance of 400 m and a volume of 0.05 $m^3 motorbike^{-1}$.

Chainsaw-winch (*CS-W*) The CS-W system is used in the extraction of wood in private (community) forests on the islands of Java and Kalimantan. The winch is locally assembled and driven by a manual or diesel power source (generator) of 22–24 PS. The winch is mounted on a four-wheeled car frame or statically assembled on frame steel (Figure 6). In the static winch system, a winch is tied to a tree as an anchor using an iron wire rope. The system is used in selective cutting in steep terrain. The CS-W work team consists of 4–6 people. The logs are pulled uphill one piece $trip^{-1}$ (Ruslim et al., 2008; Endom, 2013). The level of technology used ranges from appropriate technology to an intermediate-technology system.

According to Endom (2013), the extraction distance of the manual winch system in Java is 15 m. The average log diameter being pulled is 21.82 cm and the length is 2.14 m. The productivity of the system is approximately 0.46 $m^3 hour^{-1}$. The generator-power winch is used to extract a large log with a diameter >50 cm in Kalimantan Island. This system was previously used in the extraction of wood in a harvest permit of a natural forest concession intended for local people. The use of a generator is intended to reduce equipment, transport, and maintenance costs. This winch is

Table 2 The average productivity of tree felling several wood species using a chainsaw in private forests

Wood species	Diameter (cm)	Volume ($m^3 tree^{-1}$)	Productivity ($m^3 hour^{-1}$)	Location	Source
Sengon	23.42	0.54	3.77	East Java	Rahayaan (2023)
Teak	22.51	0.36	0.85	South Sulawesi	Mujetahid (2008)
Teak	19.60	0.32	7.17	West Java	Jenaro et al. (2018); Assegaf et al. (2023)
Meranti and *kapur*	50.00	4.12	15.11	East Kalimantan	Ghozali et al. (2021)
Gmelina (Location 1)	13.50	0.17	4.88	West Java	Sukadaryati et al. (2018)
Gmelina (Location 2)	19.30	0.37	3.39	West Java	Sukadaryati et al. (2018)
Sonokeling	N/A	N/A	1.47	Central Java	Maulana (2020)

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(a) (b)

Figure 4 Shouldered wood transport system in private forests management in Indonesia: one log (a) and two logs (b) (Courtesy: Budiaman, 2023).

(a) (b)

Figure 5 Transporting logs using motorbike in private forests management in Indonesia: the logs are placed on the both side of motorbike (a) (Source: Sukadaryati et al., 2021) and the logs are placed on the behind of the rider (b) (Courtesy: Budiaman, 2023).

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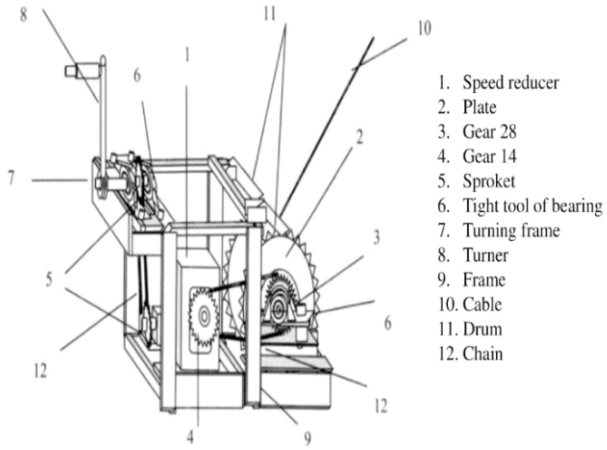

(a)

(b)

Figure 6 Pulling logs using winch: manual winch (a) (Source: Endom, 2013), and generator-powered winch (b) (Source: Ruslim, 2013).

equipped with 6–8 gears (gear) with diesel fuel. Some of these gears function as gear drives and others as well as wire rope ¾ inch in diameter. The system is operated by a working team of 4–6 people. The productivity of the system was 42.36 m^3 $hour^{-1}$, and the skidding distance was 1,207 m (Ruslim et al., 2008).

Chainsaw-skyline (*CS-SKL*) The use of the skyline system for harvesting private forests began in early 2000. Dulsalam (2006) reported that the skyline system used is a locally designed cable system with 2 drums. This system is used on undulating terrain with a slope of up to 25%. The CS-SKL uses a diesel power source with a 24.34 PS, and an engine speed of 2,200 rpm. The capacity of the main cable drum with a diameter of 12 mm is 500 m, and the system is equipped with hydraulic and manual brakes. The diameter of the logs that are transported varies from 2655 cm, with an average of 36 cm. The length is 2 m, and the number of loads per trip is varied, depending on the diameter of the logs. The volume of transported logs ranged from 0.10–0.46 m^3 $load^{-1}$ with an average of 0.20 m^3 $load^{-1}$. The cable line length was 125 m, and productivity ranged from 2.219.65 m^3 $hour^{-1}$, with an average of 4.69 m^3 $hour^{-1}$. Meanwhile, Endom (2013) reported that the use of the system in forests with small-diameter logs and short extraction distances results in low productivity. The productivity of the system was 0.63 m^3 $hour^{-1}$ with an extraction distance of 50 m. The average diameter of transported logs was 21 cm and the log's length was 2.12 m

Another skyline system used in harvesting private forests in steep terrain is the gravity skyline system (GSS). The system utilizes the earth's gravity as the power source. The work team for the system consists of 6–10 people. The productivity of GSS was 1.67 m^3 $hour^{-1}$ with an extraction distance of 300 m. The maximum extraction distance of the system was 700 m (Endom et al., 2006).

Chainsaw-tractor (*CS-T*) The CS-T is used to harvest private forests in Berau, East Kalimantan Province. A group of forest farmers manages a natural forest whose status has been changed to a private forest (locally known as "*hutan hak*"). The private forest already has a timber legality verification standard from the Ministry of Forestry and Environment. In this system, the tree is felled with a chainsaw and bucked into tree length. The average diameter is 50 cm and the log's length is 21 m. The bucked log was then skidded using a 200-horsepower tractor. The average productivity of the system was 25.1 m^3 $hour^{-1}$ with an average skidding distance of 222,2 m (Ruslim et al., 2020; Ghozali et al., 2021). The average productivity of several harvesting systems in private forests is presented in Table 3.

The management and harvesting of private forests have shown positive developments. However, there are still various technical, planning, institutional, and political problems (Riyadi et al., 2013; Soedomo, 2014; Aminudin et al., 2020, Hermudananto & Supriyatno, 2020), The form of private forest management in Indonesia can be classified into 2 major groups, namely 1) single management by owners and 2) joint forest management (Kusumedi & Nawir, 2010). In general, private forest harvesting is carried out by harvesting contractors, who are the communities around the forest (Anatika et al., 2019). In single forest management, farmers

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Table 3 The average productivity of several harvesting systems in private forests

Harvesting system	Productivity (m^3 $hour^{-1}$)	Extraction distance (m)	Source
Chainsaw-human power (shouldered system)	0.33	150	Endom et al. (2006)
Chainsaw-human Power (carried system)	0.45	120	Endom et al. (2006)
Chainsaw-animal	0.37	100	Tinambunan and Sukadaryati (2009)
Chainsaw-motorcycle	1.58	100	Basari (2010)
Chainsaw-motorcycle	0.85	400	Sukadaryati et al. (2018)
Chainsaw-winch (manual)	0.46	15	Endom (2013)
Chainsaw-winch (generator)	2.36	1,207	Ruslim et al. (2008)
Chainsaw-skyline	4.69	125	Dulsalam (2006)
Chainsaw-skyline	0.63	50	Endom (2013)
Chainsaw-skyline (gravity system)	1.67	300	Endom et al. (2006)
Chainsaw-tractor	25.10	222	Ruslim et al. (2020); Ghozali et al. (2021)

hire harvesting contractors in a piecework system without written work contracts and harvesting plans. In joint forest management, several private forest groups have or are currently applying for sustainable certification and standardization in sustainable forest management.

Improvements to sustainable private forest management are performed by reforming the system, which refers to a set of criteria and indicators. Some private forest communities involved in joint management have obtained certification from national or international certification agencies such as the Indonesian Ecolabelling Institute (IEI) or the Forest Stewardship Council (FSC) (Pramesthi & Haryanto, 2010; Hermudananto & Supriyatno, 2020). Therefore, they already have a sustainable forest management plan, including a harvesting plan. According to Budiningsih et al. (2019), sustained yield harvesting can be carried out by regulating the limited diameter of the cut, determining the annual allowable cut, and using a selective cutting system. Several private forest communities apply a diameter limit that may be cut. In the *sengon* private forest, the diameter limit of a tree being cut is 20 cm. According to the MoEF (2022), 94 private forest communities with an area of 3.3 million ha have obtained wood legality certification. Meanwhile, communities without certification have currently received technical assistance from NGOs (Laraswati et al., 2020).

Forest inventory is a vital tool in the sustainable management of forest resources. It provides information for forest management decisions, including forest harvest planning and assessing the economic viability of timber harvesting (Dau et al., 2015). Before the Job Creation Law is issued, a private forest inventory is conducted according to certain needs and not conducted regularly. A periodic forest inventory program initiates the Indonesian government's support in realizing sustainable private forest management. This concern is shown by the issuance of the Job Creation Law in 2021, outlined in the Minister of Environment and Forestry Regulation Number 9/2021. Based on this regulation, the government intervenes in private forest management with identification and inventory activities. Registered private forest owners will receive assistance with production facilities and sustainable management.

The effective implementation of sustainable forest management depends largely on carrying out forest operations in a sustainable manner. Five key performance areas to ensure the sustainability of forest operations include environment, ergonomics, economics, quality optimization of products and production, and people and society (Marchi et al., 2018). In terms of these aspects, private forest harvesting in Indonesia has not been able to fulfill the key performance, especially the quality optimization of products and production, ergonomics, and work safety. The harvesting system in private forests is motor manual. The chainsaw is the main tool for felling, debranching, and bucking. Fully manual systems, which use axes or hand saws, are no longer used in private forest harvesting. The modified motorbikes and winch are designed and manufactured by the local community, which has not been tested for the feasibility of their use, and there is no standardization of the operation yet. The operation of the winch system in forest harvesting in Indonesia does not yet have statutory regulation. At present, the existing policy instruments are only in the form of operational guidelines (Ruslim, 2013). Meanwhile, the cable system used in private forest harvesting is developed by the Indonesian Forestry Research Institute. So far, there are no regulations available for cable system operation in Indonesia. The development of drafting a regulation on the use of cable systems in forest harvesting was still at the stage of the formulation of a policy brief (Sukardayati et al., 2021).

Forest harvesting can impact the forest environment, such as damage to soil resources, water resources, landscape, fauna, and remaining stands (Sessions, 2007). Out of the 7 identified private forest harvesting systems, only motorcycle-based systems have the potential to cause a negative impact on the soil. The possible impact of the

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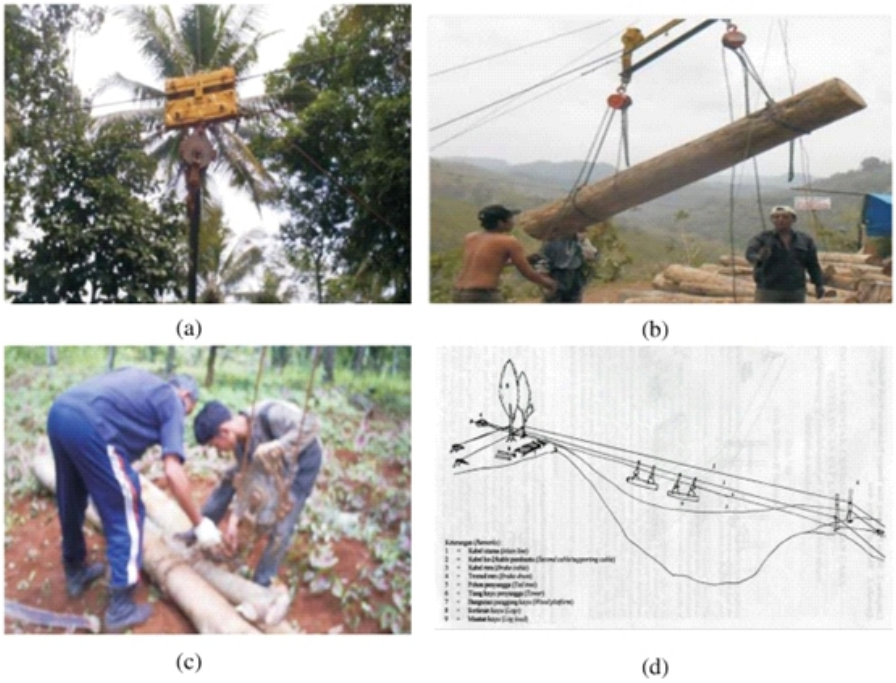

Figure 7 Transporting logs using cable system: P3HH24 skyline system (a) (Source: Dulsalam, 2012), skyline expo generation III (b) (Source: Sukadaryati et al., 2021), logs loading in the skyline operation (c) (Source: Dulsalam, 2012), and gravity skyline system (d) (Source: Basari et al., 1998).

harvesting systems is an increase in soil density on the transportation route. The use of a motorcycle will leave tire tracks on the ground traversed as deep as approximately 8–10 cm.

Private forest loggers and harvesting contractors are local communities around the forest. These workers are free employees hired to log and extract wood from the private forest. They have low levels of education and have not received special training on harvesting techniques and equipment, occupational health and safety (OHS), and work productivity. Furthermore, their forest harvesting skills are self-taught and based on long work experience. Harvesting contractors in the private forest have low knowledge of OHS, hence the risk of work accidents is high. According to Yovi and Yamada (2019), the death rate for forestry workers is 1.3 deaths per 106 m^3 logs. However, this value may be higher in reality because it only represents data taken from formal workers, while loggers and skidders are informal workers. This indicates that there is still much to be done to improve standard operations in private forest harvesting.

Even though private forest harvesting faces many problems, from a social, technical, institutional, and economic perspective, it has positively impacted the economy and welfare of Indonesian people living in rural areas (Sylviani et al., 1996; Aminah et al., 2013; Sabilla et al., 2017). Private forest harvesting employs the stakeholders involved, including private forest owners and communities around the forest who work as felling and skidding contractors (Achmad et al., 2015; Widarti, 2015; Anjarsari et al., 2022). In addition, private forests contribute to the daily food supply of private forest farmer households (Apriyanto et al., 2016; Lestari et al., 2018; Irundu & Fatmawaty, 2019).

Conclusion

This research collects important information about the current conditions, problems, and developments in private forest harvesting systems in Indonesia. It evaluates work systems and harvesting productivity used in 4 major islands, such as Java, Sumatra, Kalimantan, and Sulawesi. The forest harvesting carried out is ground-based and cable-based, and the cut to length method used is more dominant than tree length and sawn timber methods. The harvesting system most commonly needed in the 4 major islands is a chainsaw-human power and modified motorcycle system. The developments toward intermediate technology are starting to be seen with the growing use of winch and skyline systems, especially in Java and Kalimantan Island.

Recommendation

The main problems of private forest harvesting include technical, planning, and ergonomic issues. The role of the government and related stakeholders needs to be increased in overcoming this problem. The standardization of operations, certification of harvesting contractors, training in chainsaw maintenance, harvesting techniques, and OHS should be conducted to improve the quality of private forest harvesting in Indonesia.

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