Traditional knowledge and sustainable agarwood cultural practices among Indonesian ethnic communities

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Research

Abstract

Background: *Gaharu*, also referred to as oud or agarwood (*Aquilaria* spp.), is one of the oldest fragrant substances, possessing profound cultural and economic importance. The historical utilization of agarwood by several ethnic groups globally has been recorded since ancient times. The elevated global demand for agarwood has resulted in problems like overharvesting, exploitation, and illegal trade that are threatening natural populations and market sustainability. There is also a lack of information on the traditional knowledge of indigenous people or ethnic groups involved in collecting and utilizing agarwood. This research is an attempt to explore the sustainability of agarwood cultural practice among generation

of ethnic communities and empirical scientific evidence support their uses. We determined variable grading criteria (smell, resin color and density/texture) in different ethnic communities across the islands and show how home-garden cultivation enables a sustainable supply in accordance with ritual longing.

Methods: Ethnoecological studies were conducted based on in-depth interviews carried out with 2-13 key informants for each ethnic communities across Indonesia archipelago (main islands of Indonesia, i.e. Sumatra, Java, Kalimantan, Nusa Tenggara, Sulawesi, Maluku and Papua).

Results: This article reveals the ethnobotanical diversity of agarwood, reflected in variations in naming, use, and perspectives across ethnic groups in Indonesia. These findings demonstrate that agarwood is not merely an economic commodity but has been deeply integrated into an embodied cultural entity. The convergence of ethnographic data with historical sources—both Nusantara manuscripts and colonial records-confirms that knowledge and use of agarwood have been ongoing for a long time. The interdisciplinary approach in this study demonstrates the alignment between traditional practices, such as medicinal uses, and scientific evidence regarding the chemical composition of agarwood. Furthermore, despite declining natural availability due to deforestation, agarwood remains sustainable through cultivation efforts. This practice is driven not only by commercial value but also by cultural and religious needs, confirming the continued role of agarwood in the socio-cultural system of society

Conclusion: The cultural significance of agarwood utilization in ethnic communities should not be overlooked, and this knowledge is a national heritage. And we need scientific evidence to support the anecdotal evidence of those traditional practices.

Keywords: Agarwood, Indonesia, local community, traditional knowledge

Background

Aquilaria and *Gyrinops* species are very important due to their high economic value as a source of agarwood, which is in great demand for its fragrance and medicinal values giving rise to substantial domestic and international trade. Indonesia is one of the major producing countries and earned valuable foreign exchange (Burkill 1966, Lee *et al*. 2022, Turjaman *et al*. 2025). Agarwood is employed ritualistically as incense, in perfumery and for medicinal purposes across Southeast and East Asia and the east of the Middle East. It is also mentioned as major substances in major religious traditions and was written in colonial era and Nusantara manuscripts (Compton & Ishihara 2004, Grami 2013, Jung 2013, López-Sampson & Page 2018, Marinucci 2023, Yunjun 2013, Zohar & Lev 2013, Harrathi & Kipling 2023, Royyani *et al*. 2024).

Yet with such a history, documentation at community level in Indonesia remains sketchy. There is a noticeable paucity of systematic reviews on local grading systems and being familiar with the criteria (e.g., aroma, resin color, density/texture) that guide harvesting, selection and trade. A further tenuous link between such practices and proven phytochemical evidence on bio-active resins exist. Moreover, the applications of traditional ecological knowledge in sustainability practices and management are not well understood. Existing literature has often emphasized factors, forstering trade economics, medicinal values or aromatherapy but does not touch on the depth of how various ethnic communities in Indonesia make use of and exchange practical knowledge to adapt them into a sustainable practice (Ali *et al*. 2016, Bhuiyan *et al*. 2009, Chitre *et al*. 2007, Gogoi and Buragohain. 2023). This situation underscores the need for a sustainability framework integrating culture, biodiversity, and management (Soini & Dessein 2016, Strang 2024, Strang & Luetz. 2025).

A traditional foundation for management in culture: Indonesia's significance as a producer, the long but complex history of use across cultures and time and locally held knowledge all provide strong economic rationale for culturally based management (Burkill 1966, Lai *et al*. 2025, Turjaman *et al*. 2025, López-Sampson & Page 2018). Publication on community-based response practices and grading heuristics is minimal; linkages to phytochemistry or particular sustainability practices are not evident (Donovan & Puri 2004, Keim *et al*. 2020, Turjaman *et al*. 2025). The development of local heuristics may facilitate nondestructive field screening, quality control and cultivated supply chains consistent with cultural demand (Soehartono & Newton 2002, Soini & Dessein 2016).

This paper explores the traditional knowledge of various ethnic groups in Indonesia, particularly those on the larger islands. The article seeks to answer two fundamental questions. First, does the knowledge and use of agarwood by these communities have a historical basis? Second, does the knowledge and use of agarwood by these communities align with

scientific data? A hypothesis holds that knowledge and use of agarwood are considered cultural sustainability (Wagner 2012; Soini & Dessein 2016). To assess the cultural sustainability and current understanding of agarwood utilization, old Indonesian manuscripts and colonial-era sources were examined. Furthermore, literatures on the active chemicals found in agarwood and their roles in medicine and other uses known to the community were compiled and discussed.

Materials and Methods

Research location and period

A series of field interviews, executed in several phases from 2008 to 2025 covered 27 ethnic communities across the Indonesian archipelago. The research locations were selected based on reports of agarwood-related activities, including direct extraction in the forest, processing of derivative products at the village or ethnic community level, and trading activities. Even though the research activities were carried out over a relatively long period, this was not considered to reduce the reliability of the research. In general, the ecological changes resulting from the decline in the natural agarwood population between 2018 and 2025 could prompt agarwood hunters to move farther from settlements in search of natural agarwood sources. However, regulations and trade remain unchanged, as they are still governed by CITES Appendix II, and local traders continue to determine the selling price of agarwood. Science and technology may impact communities seeking modern agarwood inoculation methods, but are limited by funding and the inability to obtain effective inoculants for agarwood production. The geographical dispersion of the data collection sites and period is further depicted in Figures 1 and Table 1. Figure 2 illustrates the distribution of agarwood-producing tree species across the Indonesian archipelago. The distribution data were compiled from field observations documented by researchers from Indonesian research and forestry institutes, verified herbarium specimens (deposited at Herbarium Bogoriensis and the Center for Sustainable Forest Development Herbarium), and corroborated by established scientific literature (e.g., Lee *et al*. 2018, 2022, Susilo *et al*. 2014a, 2014b, Suhartono & Newton 2002).

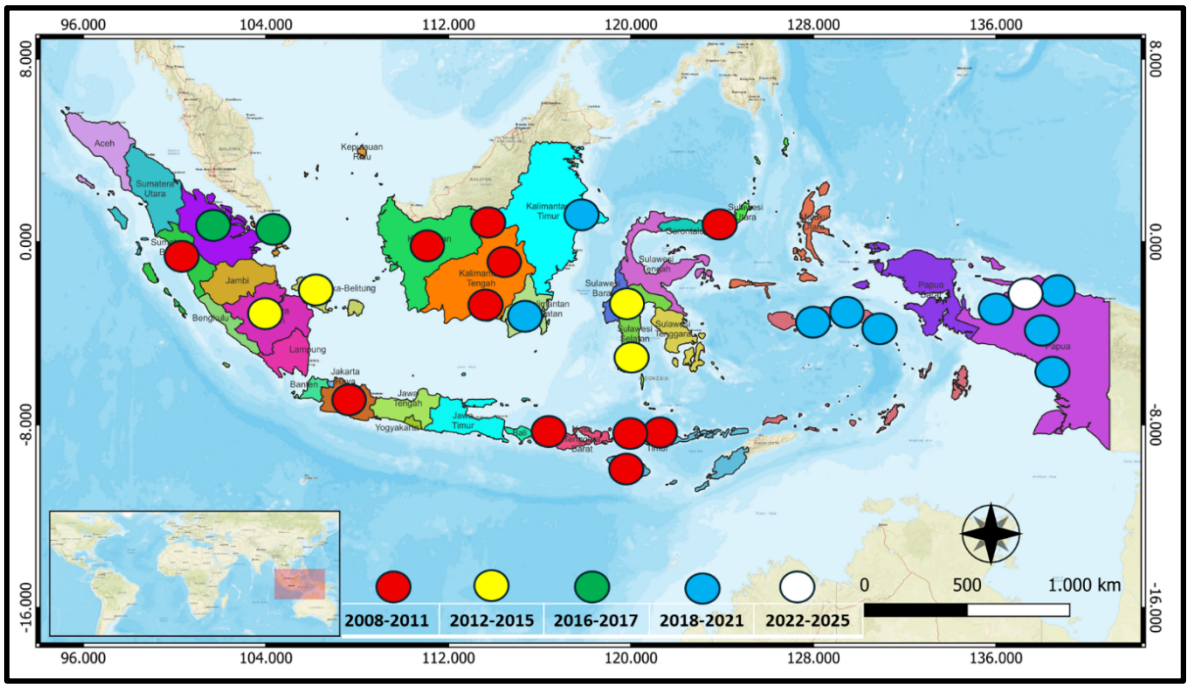

Figure 1. Distribution of location and time in data collection across community ethnics in Indonesian archipelago

Data Collection

This exploratory research investigates traditional knowledge of agarwood utilization among various ethnic communities in Indonesia. Data were collected through semi-structured interviews. Prior to each interview, selected key informants were briefed on the research scope and objectives. Informed consent was obtained, ensuring their agreement for the non-commercial, academic dissemination of the information they provided. The first group of questions covering the exploration of local taxonomic knowledge and the parts of the trees used. This interview was conducted using an open-ended interview method. In this process, the research team, among them are also botanists, directly identified the type of agarwood tree in question by observing the agarwood leaves found in the research area, thus allowing specimen vouchers not necessary to be taken and deposited. To support direct species identification in the field, several supporting documents were used,

including: a) Photos of herbarium specimens of various types of agarwood-producing trees from the collection of the Herbarium of the Forest Development Center - Ministry of Forestry; and 2) Books on the introduction of agarwood-producing tree species from the Genus *Gyrinops* (Susilo *et al*. 2014) and *Aquilaria* (Susilo *et al*. 2014). The next stage in the data collection process is in-depth interviews. The purpose of these in-depth interviews is to explore the beliefs, myths, meanings, and cultural values of agarwood. The long-standing relationship between researchers and the community helps build trust, allowing key informants to provide information without hesitation. Interviews were conducted in local languages to obtain in-depth and authentic information from the local community. A local translator fluent in Indonesian was involved in each session to ensure accurate communication. Each interview lasted 1 to 2 hours per respondent. The data collection period at each research location varied between 5 and 12 business days.

Table 1. Data Collection Sites and Periods Across the Indonesian Archipelago

Sumatera mainland and the islands (N)	**Kalimantan (N)**	**Java (N)**	**Papua (N)**	**Sulawesi (N)**	**Maluku (N)**	**Nusa Tenggara (N)**
Melayu of Bangka Belitung Island (6)	Banjar (10)	Java (5)	Asmat (7)	Minahasa (5)	Alifuru (6)	Ngada (3)
Melayu of Riau (5)	Dayak Meratus (8)		Sobey (5)	Toraja (5)	Nuaulu (6)	Lombok (8)
Melayu of Batam Island (5)	Dayak Iban (13)		Waropen (3)	Makasar (5)	Wemale (4)	Mutis (2)
Melayu of Palembang South Sumatera (5)	Dayak Ngaju (11)		Dani (5)			Sumba (2)
Minagkabau of West Sumatera (4)	Dayak Kenyah (6)		Didam (4)			
	Dayak Kayan (5)					

Note: numbers in the brackets show the number of key informants in each location

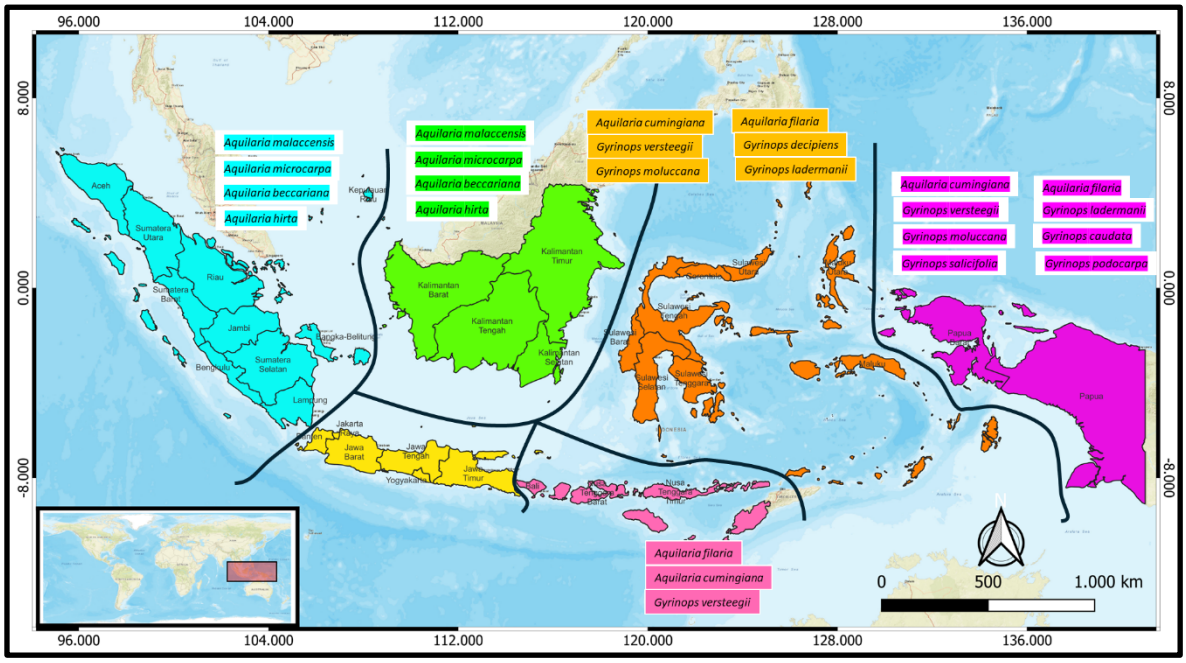

Figure 2. Distribution of agarwood-producing tree species from the genera *Aquilaria* and *Gyrinops* across the Indonesian archipelago

Ethnographic studies with a material perspective are very helpful in analyzing traditional knowledge about agarwood. In this context, agarwood is not seen as merely a material, but also as a culture in itself that "must be heard" (Strang 2024). Materials that relate to each other (Latour 2005) become a link or connectivity between humans and space (Tsing 2015). In selecting key informants, one or more criteria must be met: a) Individuals who work as agarwood collectors; b) Traditional healers who have long been and are accustomed to being referred to by the community for treatment; c) Those over 40 years of age, indicating social standing and experience within the ethnic group; d) Those born and raised in the village where the research took place, demonstrating the local authenticity of the key informants. The number of key informants for each ethnic group varies, depending on the number of individuals who meet one or more of the above criteria. The total number of key informants interviewed in this study was 153 people with distribution details as in Table 1. Not only conducted in multiple sites, the data collection was also conducted in several time period (Fig 1). A systematic search was done in literature sources including five ancient Indonesian classic scripts referring to traditional medicine and ritual scripts; *Serat Centhini* (1814-1823), *Kitab Attibb* (1889), *Hikayat Raja-Raja Pasai* (1383-1390), *Bustanus Salatin* (1637), and *Hikayat Hang Tuah* (1688-1710). Secondary literature was obtained from scientific journal articles, academic publications from university libraries, and archival materials including travel reports and Dutch colonial records. The schematic of the data collection and analysis process in this study as described in Figure 3, while documentation on activities during interview and field visit was presented in Figure 4.

Integrative, "change-and-continuity" triangulation

We integrated colonial archival analysis, hermeneutic interpretation of Indonesian/Nusantara manuscripts, and participatory ethnography into a cohesive triangulated framework. Historical sources outline longstanding patterns; modern interviews provide context for their interpretation; and collaborative analysis implements a "change-and-continuity" framework that regards all sources as an interconnected dialogue rather than separated datasets. Evidence is obtained from ethnographic interviews, confirmed by Dutch colonial records and Nusantara manuscripts; this integrative methodology connects traditional knowledge with contemporary facts to evaluate environmental challenges to agarwood sustainability.

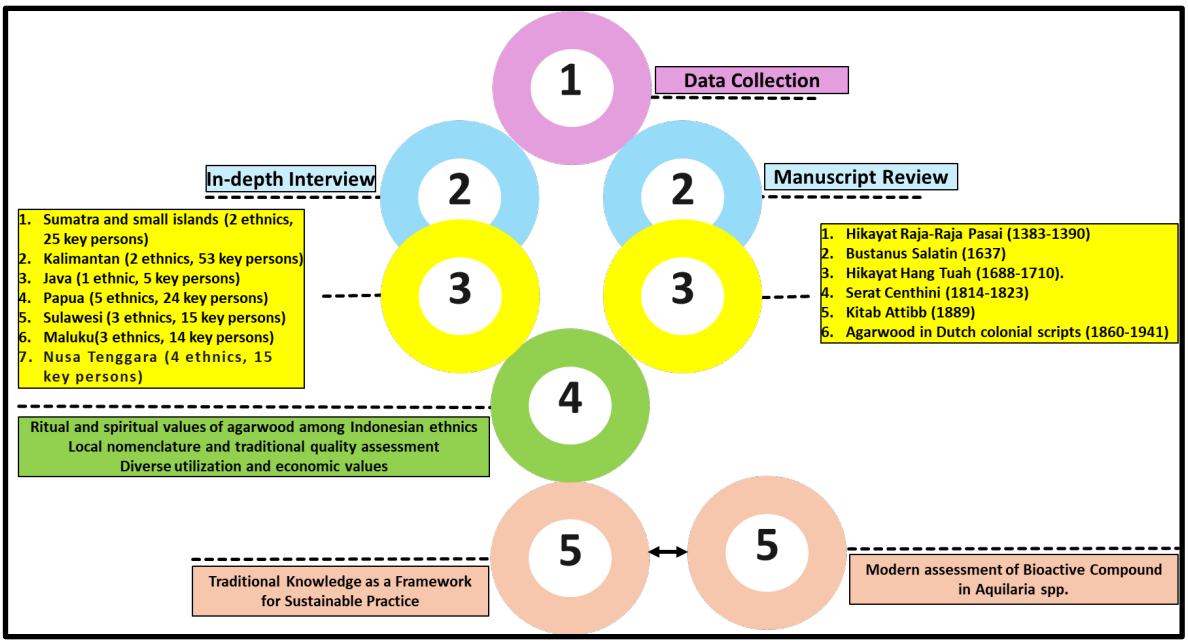

Figure 3. Schematic of the Data Collection and Analysis Process

Results and Discussion

Distribution of Agarwood-Producing Species in Indonesia

Agarwood is a desirable secondary metabolite produced in reaction to fungal infection, primarily in tree species of the family *Thymelaeaceae*. The primary genera that produce agarwood are *Aquilaria* and *Gyrinops*; though some other species, including *Aetoxylon, Enkleia*, *Wikstroemia*, and *Gonystylus*, also generate resin of typically lower quality (Li *et al.* 2023). The genus *Aquilaria*, initially characterized by Lamarck in 1783, include 21 species (Soehartono & Newton 2002) found from the Himalayan foothills to southern China, Indochina, the Malay Peninsula, Indonesia, and New Guinea (Lee & Mohamed 2016). The genus *Gyrinops*, discovered by Gaertner in 1807, compromise nine species distributed throughout Southeast Asia and the Pacific Islands, particularly in Indonesia, Papua New Guinea, and Sri Lanka (Hou 1960). Morphologically, *Gyrinops*

resembles *Aquilaria*, however it differs in pericarp thickness and the configuration of the aril covering the seed (Ng *et al*. 1997).

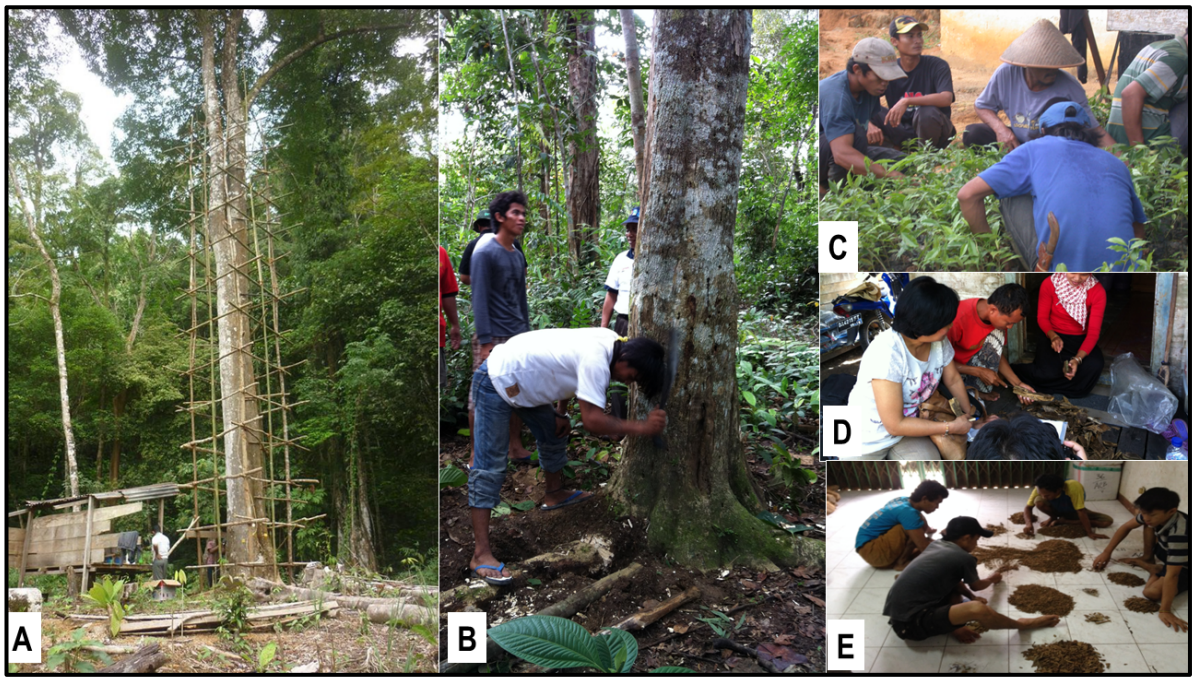

Figure 4. Finding respondents to interview began with searching for sources of *Aquilaria malaccensis* agarwood trees growing naturally in North Sumatra (A); They monitored and maintained the condition of *A. malaccensis* trees growing naturally around residents' gardens in South Kalimantan (B); We asked a series of questions to agarwood farmers who are preparing *A. malaccensis* seedlings (C); conduct further interviews when they are carving agarwood at home (D); and interview middlemen traders about how they grade agarwood and determine the price for each grade of agarwood to be exported to other countries (E).

Indonesia serves as a hub of diversity for agarwood-producing species, especially within the genera *Aquilaria* and *Gyrinops*, with their populations extending from Sumatra to Papua. In western Indonesia, *Aquilaria* species are predominant, whereas *Gyrinops* dominates the eastern regions. *Aquilaria* cumingiana naturally occurs in the forests of Sumatra Island, which covers areas in Aceh, North Sumatra, Jambi, West Sumatra, and partially Bengkulu. Like Sumatra, Kalimantan also has significant populations of agarwood-producing trees, primarily natural trees such as *Aquilaria* beccariana and *Aquilaria* malaccensis. Kalimantan is a major producing region, and there is growing interest in developing wild agarwood resources due to high demand. Important sanctuaries exist in areas such as Kayan Mentarang National Park and Betung Kerihun National Park. Local communities and industrial companies are beginning their own agarwood plantations in Kalimantan. In contrast, there are no agarwood trees native to Java; any references to agarwood there involve introduced or cultivated species

Central, Southeast, and South Sulawesi also host *Aquilaria cumingiana* and *Gyrinops decipiens*. Papua is known for its high biodiversity, home to plants like *Aquilaria filaria Gyrinops versteegii, G. moluccana*, and *G. ledermannii*, which are found naturally in regions such as Sorong, Fakfak, Manokwari, Jayapura, Merauke, and the Aru Islands. Traditional hunting of wild agarwood-producing tree species is still prevalent across Indonesia, impacting the species' existence in the country. Wild populations of *A. cumingiana* have been reported to have declined dramatically since the 1980s and 1990s due to overharvesting. However, some native residual populations continue to survive in protected areas like Batang Gadis National Park and Bukit Tigapuluh National Park. The decline in the wild agarwood production has led local communities to cultivate this plant on their own lands. In the Papua region, traditional hunting primarily relies on wild stocks, and Papuan agarwood sourced from *G. caudata, G. versteegii, and G. moluccana* is particularly valued for its high aromatic quality.

Throughout the archipelago, wild populations face similar threats driven by factors such as overharvesting, habitat conversion, and insufficient implementation of protection measures (Thi *et al*. 2024, Thompson *et al*. 2022, Turjaman & Hidayat 2017). The varying exploitation patterns and tree characteristics across different islands require tailored management strategies. Additionally, the simultaneous push of growing market demand, coupled with ineffective

government regulation, has led to extraction practices that often overlook best practices, leading to destructive and unsustainable behaviors.

Utilization and cultural perspective of agarwood

Not only do local names differ based on island or ethnic group, but even within the same ethnic group, agarwood has several local names. For example, of the six ethnic groups interviewed on the island of Kalimantan, more than 20 local names were recorded for agarwood. Even within a single ethnic group, agarwood has various local names. For example, the Dayak Iban people in Kalimantan have several local names for agarwood, namely *Bongkang, Kulang, Sakar Iban, Tinung, and Pekuk*. In addition to the diverse local names, the use of agarwood by various ethnic communities is also diverse, indicating the richness of local knowledge among various ethnic groups in Indonesia. To Minang ethnics, agarwood acknowledged by its diverse use and benefit, however its diverse use is currently hidden as its commercial resin product masked others uses," *Pohon gaharu ko aslinyo banyak manfaaik, tapi karano urang labiah tau kayu gaharu maha, manfaaik lainyo acok ndak tampak*. Banjar ethnic in South Kalimantan has long been using agarwood to treat certain disease as one of the ethics leaders said, "*Gaharu kawa dipakai gasan maubati banyak panyakit. Daun gaharu dijarang wan dicampurakan lawan ramuan lain*". To Dayak Ngaju ethnic, agarwood plays as important product in trade and also medicine, "*Ikei dia hanya menduan hampulur gaharu, ikei kea manduan dawen gaharu akan obat*". The use of agarwood in incense and also medicine has long been also practised in Toraja ethnic of Sulawesi, "*Natandaimo to buda kumua iate gaharu bisa dipadadi dupa, apa sitonganna buda duka pa tu manfaat senga'na, susinna dipake ma'popedampu. Mintu' torroanna te tananan bisa nasang dipake ma'dampi*". Besides its role in traditional medicine, for Naulu ethnic of Maluku agarwood also stand as a sacred tree, "*Alolasie rer no ai arinani sio anata, oso sakai na re barakati. nae eta ai reimo sionata asuma oso itamo sopa tau rei*". For Alifuru ethnic, agarwood is also a blessing tree in religious rituals, "*Gaharu na kau fili dato' moyang' fuke msian haluk berkati kau na pese oleh data' moyang' nanik na roh haluk kita ma menyembah deuk peni*". Not only well known for its medicinal and religious uses, agarwood also has been utilizing in cosmetics and female hygiene as practiced by Javanese communities, "*Gaharu punika salah satunggaling bahan ingkang wigati kagem ratus. Wonten ing racikan ratus, gaharu saged dipun gantos bahan sanèsipun, nanging ngginakaken gaharu langkung sampurna*." To those explorative uses of agarwood, it is apparent that agarwood encompasses various aspects, including spiritual, social, economic, cultural, and medicinal purposes across various communities' ethnics in Indonesia. Agarwood is also known as a multipurpose tree, as interviews revealed that all parts of the tree are used for various purposes (Table 2).

Following the tabulation of interview data from key informants across all studied ethnic communities, agarwood was predominantly reported as a trade commodity (26%). Notably, a novel application was identified: the use of agarwood bark as rope or binding material for various purposes during forest activities. This specific utility has not been documented in prior literature. To date, the benefits and uses of agarwood for cultural rituals, traditional medicine, and religious rituals have also been validated and are still widely practiced (Figure 5)

Table 2. Interview results related to the local name for agarwood, its part and ethnobotanical use by community ethnics

Main Island	Ethnicity	Local name	Ethnobotanical uses	Part used
Kalimantan	Dayak Ngaju (Central Kalimantan)	*Garu, Garu Manyan, Pekuk, Takung, Sakar*	a) Local name refers to agarwood utilization as a religious ritual and sacred belief. b) Traditional medicine (breathing problems, stress, headache). c) Custom ritual. d) Rope. e) Trading.	Agarwood chips, Leaf, Bark
	Dayak Iban (West Kalimantan)	*Bongkang, Kulang, Sakar Iban, Tinung, Pekuk*	a) Refers to gaharu plant and agarwood chips quality. b) Traditional medicine. c) Custom ritual. d) Trading. e) Rope.	Agarwood chips, Bark, Wood, Leaf
	Dayak Meratus	*Sakar tua, Bongkak, kulung, tunak, sakar ngelang*	a) Refers to name of place and local conservation or sacred site. b) Traditional medicine. c) Rope. d) Custom ritual. e) Trading.	Agarwood chips for ritual, Leaf, Bark, Wood
	Dayak Kenyah (North Kalimantan)	*Dagun, Tubu, Menggau*	a) Refers to utilization for custom ritual. b) Traditional medicine. c) Rope. d) Trading.	Agarwood chips, Leaf, bark, wood

	Dayak Apo Kayan (East Kalimantan)	*Bongkak, Kulang, Tinung, Sakor Apo, Mengalut*	a) The local name refers to relationship between spirituality and customary ritual. b) Traditional medicine. c) Rope. d) Trading.	Agarwood chips, Wood, Bark, Leaf
	Banjar (South Kalimantan)	*Gaharu, Gaharu Kuning, Gaharu Tengah, Kemangkur*	a) The local name refers to common Indonesia language and the gaharu quality. b) Wood for custom ritual (respect to the ancestor) and natural fragrance. c) Agarwood chips and infected wood as trading though sorting the wood quality. d) Traditional medicine (stress, breathing problems, sedative). e) Rope. f) Trading.	Agarwood chips, Wood, Bark, Leaf
Papua	Dani (Wamena)	*Lekkik*	a) The local name refers to part of the gaharu plant or wood that has been rotted and emits a specific aroma, b) Agarwood chips and infected wood as trading through sorting the wood quality. c) Rope. d) Traditional medicine, e) Trading.	Agarwood chips, bark, wood, leaf
	Asmat (Asmat, South Papua)	*Kukuk and Sisik*	a) The local name refers to the relationship between man and the cosmic and ancestor spirit. b) Sisik refers to the shape of gaharu wood that has good quality. c) Agarwood chips and infected wood as trading through sorting the wood quality. d) Carving and natural jewellery. e) Rope	Agarwood chips and Wood
	Didam (Waropen)	*Pisik, Rakus, and Oyak*	a) The local name refers to spiritual power. b) Wood for custom ritual (respect to the ancestor) and natural fragrance. c) Agarwood chips and infected wood as trading though sorting the wood quality. d) Rope.	Agarwood chips, Wood, Bark
	Sobey (Sarmi)	*Kerak or Rukus*	a) They have not belief agarwood. b) They seek agarwood just as resources for trading. c) Rope.	Bark, Agarwood chips
Sulawesi	Minahasa (North Sulawesi)	*Batu Gaharu* or *Gaharu, local dialect Gahuru*	a) Local people belief, burning gaharu will refresh relation with nature and their ancestor. b) Agarwood chips and infected wood as trading though sorting the wood quality.	Agarwood chips, Bark, Leaf
	Makassar (South Sulawesi)	*Gaharu or laksa*	a) Gaharu refers to a specific plant that is identified as *Aqualiria* spp. or *Gyrinops* spp. b) Laksa refers to all plant that are infected by fungi. c) Agarwood chips and infected wood as trading through sorting the wood quality. d) Fragrance. e) Rope. f) Custom ritual. g) Gift for respected person. h) Recite sacred books.	Agarwood chips, Bark
	Toraja	*Mamparapara* or *Lampana*	a) Ritual tradition, especially for funeral ritual. b) Local people belief when burn the agarwood will guide the spirit. c) Agarwood chips and infected wood as trading through sorting the wood quality.	Agarwood chips, Bark
Sumatra	Melayu in Batam and Riau	*Gaharu*, *Kemauh*, or *Kemarau*	a) Use for religious ritual and room fragrance, like in religious days (Eid al-Fitr and Eid al-Adha). b) Fishermen keep the wood for an amulet in the boat when going to sea. c) In Bengkalis, the agarwood as a gift for the kingdom family or the custom leader. d) Agarwood chips and infected wood as trading	

			through sorting the wood quality. e) Rope. f) Custom ritual.	
	Bangka-Belitung	*Gaharu*, *Tembang*, or *Kemauh*	a) Use in a custom ritual related to their ancestor. b) Agarwood is sacred material that saved by forest God. c) Agarwood chips and infected wood as trading though sorting the wood quality. d) Rope. e) Traditional medicine.	Agarwood chips, Bark, Leaf
	Palembang and South Sumatra	*Gaharu*, *Kemauh*, *Batu Gaharu*, or *Lubuk Gaharu*	a) They use the agarwood for religious ritual, especially in tabot tradition. b) Agarwood chips and infected wood as trading, though sorting the wood quality. c) Rope.	Agarwood chips, Bark
	Minagkabau (West Sumatra)	*Gaharu*, *Kemauh*, or *Lalau Gaharu*	a) They use the agarwood for traditional ritual to connecting the ancestor. b) Agarwood also used for fragrance. c) Some local people have agarwood forest that protected through local rule. d) Agarwood chips and infected wood as trading though sorting the wood quality. e) Rope.	Agarwood chips, Wood infected, Bark
Maluku	Alifuru (Buru Island)	*Tolol* or *Tolol Jua*	a) Refers to the strong aroma. b) Their use for the local religious ritual and for offering for the ancestor. c) Agarwood chips and infected wood as trading though sorting the wood quality. d) Rope. e) Custom ritual.	Agarwood chips, Leaf, Bark
	Nuaulu (Seram island)	*Lemur* or *Umu Lemur*	a) Their belief the agarwood is mother of blessing. b) Rites of passage (maturnity). c) Traditional ritual especially for purification of the spirit, d) Offering the ancestor. e) Agarwood chips and infected wood as trading though sorting the wood quality. f) Rope. g) Traditional medicine.	Agarwood chips, Wood infected, Bark, Leaf
	Wemale (Seram Island)	*Ko'o* or *Ko'o Rua*	a) They belief that agarwood is a gift from God for human. b) Before harvesting they making ritual or worship. c) They have local calendar to determine the best moment. d) Offering the ancestor. e) Agarwood chips and infected wood as trading though sorting the wood quality. f) Traditional medicine. g) Rope.	Agarwood chips, Wood that infected, Leaf, Wood, Bark
Nusa Tenggara	Ngada (Ngada, Flores)	*Sasal* or *Mbo'u Sasal*	a) They belief that agarwood has soul, before harvesting they should pray or worship. b) Sasal mean holy that must be respected. c) Burning agarwood for death ritual to guide the who died to heaven or ancestor place. d) Agarwood chips and infected wood as trading though sorting the wood quality. e) Rope. f) Traditional medicine.	Agarwood chips, Wood that infected, Bark
	Sasak (Lombok)	*Gaharu, Sawo Gaharu, or Sikar Gaharu*	a) Traditional ritual (for land cycle, and save forest). b) Social status. c) Agarwood chips and infected wood as trading though sorting the wood quality. d) Rope. e) Traditional medicine.	Agarwood chips, All part of plant use for traditional medicine
	Dawan (Timor tengah Selatan)	*Nau* or *Nau Gaharu*	a) They belief that agarwood is sacred plant. b) Given by the God of land. Agarwood plant has soul, people should respect. c) Agarwood chips and infected wood as trading though sorting	Agarwood chips, All part use as traditional medicine

			the wood quality. d) Rope. e) Traditional medicine.	
	Sumba (west Sumba, Sumba Island)	*Pura* or *Lembu Pura*	a) They use the agarwood for guide the ancestor to the end of journey (heaven). b) Traditional ritual especially for kingdom family. c) Social and custom status. d) Agarwood chips and infected wood as trading though sorting the wood quality. e) Traditional medicine. f) Rope.	Agarwood chips, All part of agarwood for medicine
Java	Jawa	*Gaharu, kemedangan, kemenyan*	a) Religious ritual. b) Custom ritual (Wedding). They belief giving gaharu in Ratus tradition will give women more good aroma), paddy planting. c) Trading.	Agarwood chips

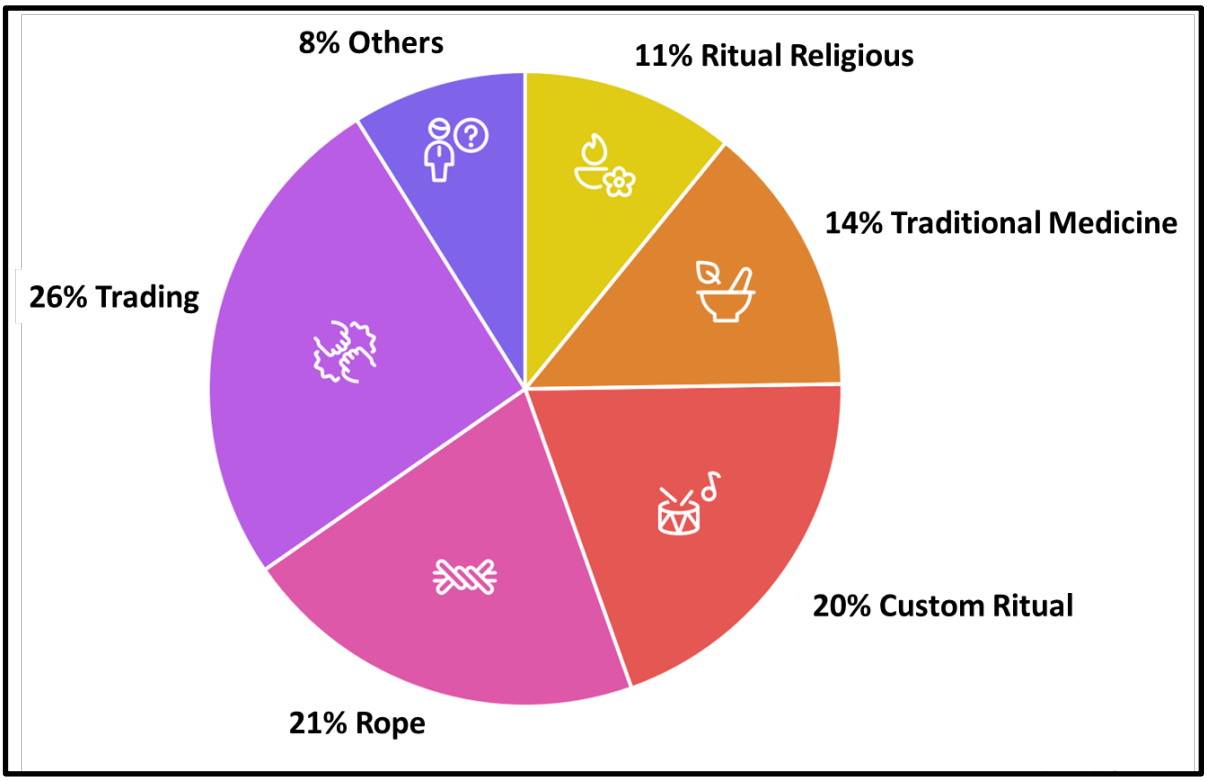

Figure 5. Primary Applications of Agarwood and Derived Products among Indonesian Ethnic Communities

Agarwood in Dutch Colonial Script

Agarwood is an important trade commodity at both the national and international scene. Our older records show that there were those trees within Indonesia's forests." Sumatran Forest had been found to be a natural habitat of this produce by Miquel (1860). An observation on a journey to Kalimantan in 1925 was that the abundance of *Aquilaria* trees was still strong in the forests there (Buijs *et al*. 1927). Local people near to these forests have indigenous debt of knowledge on that agarwood. In the Indonesian community, many aromatic natural products produced by plants have been used such as agarwood (*Aquilaria* spp.) and Kasturi (*Juniperus* spp.). The word agarwood is derived from the Arabic word *'ūd* (عود), meaning "wood". The term was originally applied broadly to different wood types but has since been narrowed to refer specifically to resinous agarwood (Boorsma 1912). One account indicates that the highest quality agarwood originates from trees that have fallen naturally.

Apart from *gaharu* or *garoe* the product is known in the area under local names like *makas*, *kalamba*, *kalarnpa* and also as *kalambak* (Gonda 1936). *Merkwaardig is evenwel, dat Mal. Kelembak= I, iets zeer goed riekendhout (van de Aquilaria malacensis); 11, hij Chineesche rabarber beteekent. Best stinkhout van deze boom verkrijgt men tamelijk verrot uit den omgevelden boom. Behalve garoe enz. vinden we als naam Makas. Kalamba, Boeg. kalarnpa, Mal. kelcmbak; alles Aquilaria*

Aquilaria malaccensis Lam. (Gonda 1936). Wild agarwood is rare, and local communities many times believe in magical beings that make the wood disappear. Some harvesters believe some rituals must be performed to increase chances of finding agarwood tree in the forest. Spirits ("*hantu*") are sometimes considered necessary to recognize these trees, in some cases.

This study revealed that ethnic communities also practice agarwood grading and have different agarwood grading criteria. This variability may be due to the absence of formal standard grading reference and varying interactions with local traders. Traditional grading at local seller involves the non-destructive identification of natural ant holes in agarwood-producing trees. The resulting resinous chips are extracted and assessed, often by olfactory evaluation of their scent when lightly burned. Additionally, chip density is traditionally assessed by immersion in water, where buoyancy indicates quality. In general, agarwood with thick resin (5-10 mm) and a distinctive sweet aroma is considered high quality and has greater economic value. These quality criteria are scientifically important because they can indicate certain active compounds and also determine economic price. Dutch colonial script also determined grading practice in local communities that classified agarwood into three grades: *kayu gaharo*, *kayu buaya* and *kayu laka*. The superior quality agarwood is produced by *A. microcarpa* (Ozinga 1940). Local communities claim that *Dalbergia parviflora*, which they call *kayu laka*, is the best quality of agarwood. This is usually found in swamps, comes red and smokes a very nice flavor. Agarwood has been traditional commodity in trade with China for hundreds of years and good quality as incense (Ozinga 1940). In India, this product has been used for several purposes including medicine, perfumery and cults (Brill 1941).

The use of agarwood and specific utilization by local communities is well documented from the colonial era. Agarwood was commonly used as one of the ingredients in the traditional formulations in combination with other agents (Dongen 1913). The Javanese also use agarwood to practice *jampi-jampi* (incantations) for medicinal furnished and soil fertility spells (Maijer 1918). The Javanese shamans showed marked specialized usage of specific plants, as reported in the literature for a longer period than less-specialized use (e.g., *Caesalpinia* is used for weaving and agarwood 'fibers' were mentioned for its medicinal leaves) (termites by shaman from Sarawak are also part of their shaman medical knowledge), and they could have learned this directly from infant age just through generalized watching during daily activities with their mother collecting plants (Buijs *et al*. 1927).

Regarding the medicinal uses of bark materials, there is report that indicates agarwood bark has been well documented as a medicinal plant utilized among South Kalimantan local communities to treat diarrhea. A distinctive ritual was performed that included placing agarwood on the patient's neck. “Seven knots are put inside a *koelit kajoe game* (*Aquilaria malaccensis*) and this *koelit* is then bound round the sick man’s neck” (de Zwaan 1910). Agarwood is also used to reduce headaches or nausea and allow people to inhale its powerful vapor for treatment. *Bij de sakit poningmata, eene ziekte, waarbij het den patiënt voor de oogen draait terwijl hij tevens van hoofdpijn klaagt en moet braken (worden) gebrand garoe (kajoewangi waarschijnlijk het beroemde aloëhout der Aquilaria Aquilaria malaccensis), benzoe en lampang kapas (de vruchtkernen van katoenplant) de rook hiervan moet door den zieke worden ingeademd* (De Zwaan 1910).

Its use as a room fragrance is also noted in colonial records. Villages have taken advantage of all sorts of other fragrant woods, such as *kayu kasturi* from *Juniper* spp. which produce agarwood (Dongen 1913). Agarwood has been used by many ethnic groups as an important tool in their traditional ceremonies, which demonstrates the close relationship it has with local culture (Boorsma 1912). A popular practice is to house agarwood and fragrant resin in homes and more specifically in religious or spiritual venues. In the past, most of local populations unconsciously disregarded agarwood and kept them in strange places without knowing their high price (Van Eerde 1920).

Though several species can serve as substitutes for agarwood, the true source of agar fragrance was found in *Aquilaria* (Dongen 1913). Local names for traded Agarwood were known as, *Garoe tandoek, garoe kapas, garoe tenggelam, garoe timboel, garoe rames and garoe boeaya* (Dongen 1913). Agarwood has been recorded as being exported in large quantities transhipped through Singapore to supply markets such as China (Ozinga 1940).

Agarwood in Nusantara Classical Script

The use of colonial script and agarwood is already recorded in the Nusantara manuscripts (historical documents originating from the Indonesian archipelago). Scripts were written in a variety of languages and writing systems typical to the time period and area. Pegon script *Kitab Attib* Uses a modified Arabic character set for transcribing Indonesian dialects and the Malay language. In the *Kitab Attib*, it mentions that agarwood is used to treat cancer sores, headache and ocular cancer

(Astamarta & Purwanto 2020, Aziz & Yunos 2019, Sampurno 2016). The Malay is the predominant ethnic group in this manuscript.

Agarwood is referred to in the *Kitab Bustanus Salatin* (The Garden of Kings). The scripts were written around 1638 CE by Sheikh Nuruddin Ar-Raniri, a great scholar of the Aceh Sultanate during the rule of Sultan Iskandar Thani. It is an important early Malay work of the field of medicinal science (*Kitab Tib*) and fits in a special segment (Chapter Seven, Part Three) of an encyclopedia compilation covering different scientific ground. In this script, Ar-Raniri describes the qualities of *gaharu* called *'ūd* and notes that it has a "second-degree warming" effect. Whilst listing its known benefits, which include improving lung function and the fragile pit of the abdomen, strengthening liver, heart and all sense organs including hearing; it has particularly powerful actions on brain function. It was believed to dispel interior wind or hidden gas in the body. The traditional use for *gaharu* is claimed to strengthen the body, solidify organ energy and freshen the breath (Ar-Ranniri 2017). However, the word "*gaharu*" did not appear explicitly in the Javanese script of Serat Centhini. The script alludes to "*kemenyan*" (although the term used was *kemenyan*) well-known today as benzoin resin, which Javanese people use for a variety of rituals, odorous purposes and medicinal functions (Sukenti *et al*. 2002). The make-a-wish of the book, Serat Centhini, claim that "*kemenyan*" is a substance used among Javanese and Balinese ethnic societies (Sangat-Roemantyo 1990). The wood was also used as incense in religious ceremonies and at sacred sites. In the ethnic groups in Indonesia, there are 13 types of incense plants recorded including one called agarwood (Sangat-Roemantyo 1990). As a result, although *Serat Centhini* never clearly mentions the name "*gaharu*", they do describe how these aromatic wood species were used; and it is probable that at least one of them was also *gaharu*.

Agarwood has been considered by many rare and precious since ancient times. Agarwood was widely-used as a tribute to the king and bestowed upon high-ranking foreign guests. This practice is documented in the hikayat literature; for instance, the *Hikayat Raja-Raja Pasai* (The Chronicle of the Kings of Pasai) mentions: "*Setelah Sultan sudah tabal maka segala hulubalang pun masing-masing duduklah dengan martabatnya mengadap baginda itu. Orang-orang besar dari negeri itu tidak lain daripada dua orang*". One named *Tuan Seri Kaya* and one named *Tuan Baba kaya*; and that the former was entitled Sayid 'Ali Ghiyathuddin, while the latter was known as Sayid Samai'mu'ddin. After a prolonged stay and service in Samudera Darussalam under Sultan Malik us-Salih, Shaykh Ismail requested permission to return to his homeland. Acknowledging his contributions to Islamic instruction, the Sultan expressed his respect and gratitude by bestowing upon him a formal tribute (fidyah) of precious commodities, including amber, camphor, agarwood, sandalwood, incense, cloves, and nutmeg (Hill 1960). The text provides a vivid picture of the diverse economic and ceremonial uses of agarwood (*gaharu*) in three 13th-century Sumatran Sultanates. Agarwood, not a simple trade commodity but also an item of glory presentable in royal tributes to the highest religious authority.

The Hikayat Hang Tuah, a classic Malay epic, indicates that agarwood was widely used across the region, almost exclusively in the form of bars or blocks: "*Setelah dlihat oleh Sang Jaya Nantaka orang mengangkat hidangan itu, maka ia pun menyembah lalu turun, beijalan pulang ke rumahnya. Maka saudagar itu pun makanlah sehidangan. Setelah sudah makan maka diangkat orang pula hidangan nikmat pelbagai makanan dan buah-buahan. Setelah sudah makan nikmat itu, maka datang pula sirih pada jorong emas. Setelah sudah makan sirih dan memakai bau-bauan, maka datanglah anugerah persalin akan saudagar itu bertimbun-timbun gaharu dan kelambak dan kapur barus dan beberapa benda yang garib-garib yang patut dagangan di benua Keling*"(Salleh 2013).

Modern-day global market mechanisms and laws have displaced traditional trade systems based on trust and patron-client relationships. Indeed, the spiritual role of agarwood within traditional culture remains an important factor contributing to its relevance in the context of global commodification and market expansion (Soehartono & Newton 2001). The archaeological analysis employed in this study is a methodological approach that combines colonial archive analysis with Nusantara manuscript hermeneutics and participatory ethnography. There is no such thing as free-floating text, each source of data interacts with all other sources in a network of shared academic discourse.

The historical data proves out the longer-term patterns, but we need to also have current data to provide context for history. Such data integration reveals new implications for the conservation of agarwood. Traditional practices Historical records describe traditional activities that demonstrate sustainable exploitation techniques relevant to current conservation programmes. On the other hand, current market tendencies, recorded in interviews, point towards emerging constraints to be taken into account for policy planning (Zouraris *et al*. 2025).

The way in which interview results are placed within the context of colonial files and Nusantara manuscripts and studied through a "change and continuity" lens, succeeds in revealing a consistent story connecting the complicated network souh-east asian agarwood-production patterns. The cross-temporal conversation reveals that to get a grip on the complexity of this issue it would be necessary not so much to bolt together different sources of knowledge as rather avoid estranging them from each other.

Traditional Knowledge as a Framework for Sustainable Practice

Agarwood (*Aquilaria* spp.) has been used in Indonesia as incense, and so for a long time as shown in Figure 6. The use of incense burning is an important cultural tradition among Indonesian societies and is deeply ingrained as part of certain religious ceremonies and weekly celebrations. The worth of agarwood is reflected in the reliance by ethnic peoples on other plant sources when supplies of this traditional article become scarce (Sangat-Roemantyo 1990).

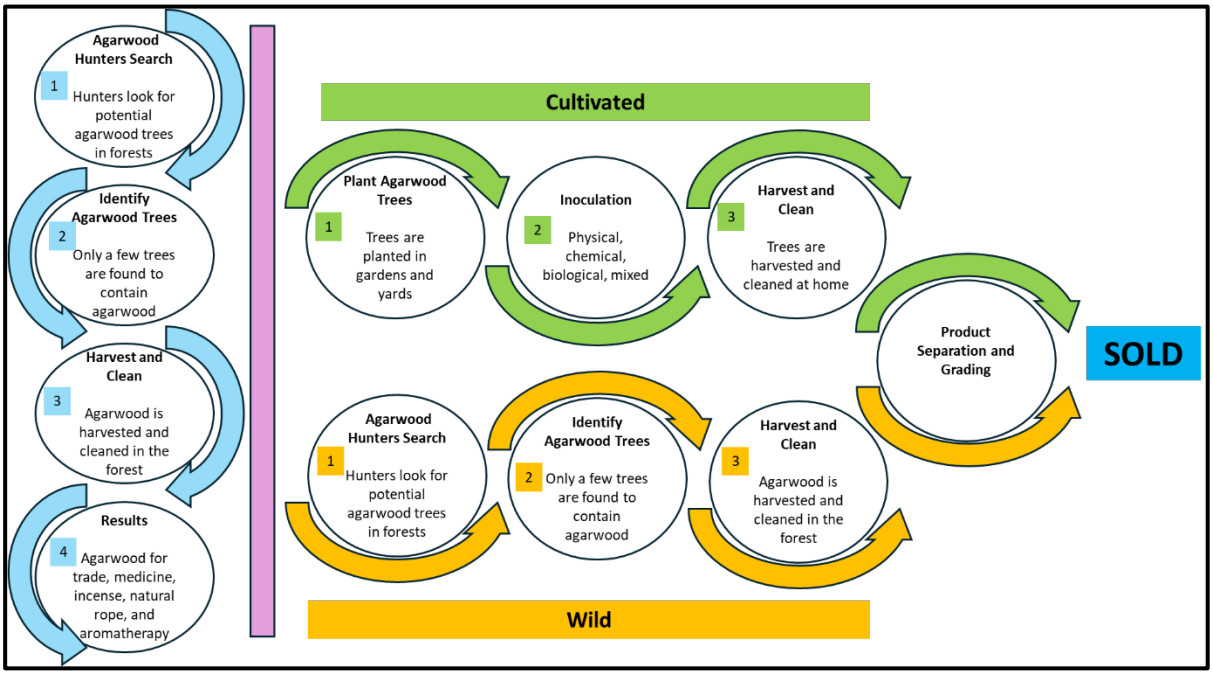

Figure 6. Old and modern practices of agarwood utilization

This long-lasting tradition reflects a notion of sustainability in culture that has always been the result of an ideal balance between environment, economy and society. This century-old tradition upholds nature, economic security and social fairness, which has enormous value for this and future generations (Parameswara & Utama 2020, Wagner 2012). The persistent information and practices on agarwood reflect continuity in both ethno-knowledge as well as resources. This reduction in agarwood tree resources however contrasts with the longevity of knowledge in collective memory and still its application. The title is universal, but the use and species preferred vary widely among regions of Indonesia. Culture specific place Since “knowledge” and “practice” are part of culture, it will naturally be attached to some physical spaces (Escobar 2001).

Exploring the relation between man and his environment is fundamentally important in designing sustainable development policy in a multi ethnics country like Indonesia. Defence of regional values and traditions must be an integral part of policy framing. It should be in line with environmental, social and economic dimensions (Parameswara & Utama 2020). Inclusion of culture in sustainability conversations is paramount because, it is the actions and behaviours of humans, which are framed by cultural influences that will ultimately determine the extent to which sustainability objectives are met (Soini & Dessein 2016). Culture is therefore more than just a social phenomenon; human-nature relationships, and environmental forces play important parts (Royyani & Bakar 2021). Therefore many traditional crafts are inherent of and comparable towards present day ideas about sustainability.

Sustainability for agarwood This is also why sustainability in the context of using agarwood isn’t just an add-one. This proximity helps growth, cultivates deepened appreciation of art, increases self-confidence and emotional resilience that contribute to lifelong learning and fulfilled living (Thani 2021). Local people commonly have practices, from harvesting to

marketing, consistent with sustainability. These are the traditions that own hundreds of years according to experiences, and influence by ecological, economic on the relationship between people and *Aquilaria* species. Agarwood is easily accessible which allows the communities to have a consistent income yield that helps conserve their culture, and values (Parameswara & Utama 2020).

To counter the depletion of wild agarwood, communities have established "agarwood gardens" on their lands. Although cultivated agarwood has a lower commercial value, it is being planted as an endowment for future generations to ensure that incense and medicine supplies can be secured. The interviews made for this research on main islands in Indonesia meanwhile, reinforce historical evidence from Dutch and Nusantara manuscripts, that suggests agarwood trading and usage serve multiple social and cultural functions. Naibei (2014) asserts that intergenerational management values are one of the manifestations of culture towards sustainable development.

The dynamism and the flexibility of traditional knowledge stand out as a hallmark. Friends have told me that some villages no longer observe conservation basics, including local customs, because the market value of birds is so high and communities are now economically commercialized. Despite these pressures, initiatives are underway to protect agarwood-producing trees whilst continuing to cultivate the trees and attempting to save the knowledge and practices of protecting agarwood through science.

Evidence from Kutai Kartanegara (East Kalimantan) reveals a clear three-stage local adaptation cycle in agarwood production over the past three decades. During the 1980s, communities relied primarily on illegal and ecologically unsustainable extraction of wild *Aquilaria*. By the late 1990s, this shifted toward semi-intensive cultivation as natural stocks declined and legal restrictions increased. More recently, communities have moved toward diversified agroforestry systems that emphasize genetic diversity and ecological resilience, a trajectory that aligns with the adaptive pathway documented by Samsudin et al. (2021).

This adaptation cycle is driven by three interrelated local mechanisms. First, producers have diversified species beyond *Aquilaria malaccensis*, reducing biological and market risks while improving long-term resource security. Second, communities have differentiated products along the value chain, moving from raw chips to higher-value processed products and by-products. Third, they have selectively adopted technologies—particularly modern inoculation techniques—filtering external innovations to fit local ecological conditions and customary management systems. Similar strategies of protecting mature trees to maintain resin quality, as observed in *Aquilaria beccariana* in Serawak (Kanazawa 2017), further illustrate how local knowledge actively shapes biological outcomes.

Periods of market or regulatory disruption, such as the 2008 - 2010 transition, did not lead to system collapse but instead triggered temporary shifts toward alternative agarwood-based livelihoods, reinforcing rather than replacing local knowledge systems. Together, these patterns demonstrate that agarwood cultivation in Kutai Kartanegara is not a linear technological transition but a cyclical, adaptive process in which ecological constraints, marker pressures, and cultural knowledge continuously interact.

Traditional Uses and Bioactive Compounds of *Aquilaria* spp.

Discussions with respondents in Sumatra, Kalimantan and Maluku indicated that the genus *Aquilaria malaccensis* has had long standing association as a component of traditional medicine among many Indonesian society. This species has good economic value and is indispensable in local medical treatment. Indigenous civilizations from different ethnicities accumulated experiences and practical knowledge through trial-and-error, regarding the characteristics of agarwood over thousands of years. Field sampling conducted in East Kalimantan has shown that the Dayak Kenyah people have used *A. malaccensis* for generations in order to treat a wide variety of diseases. A boiled resin from the tree is used to treat fever, diarrhea and constipation.

The most commonly reported Dayak ethnic communities interviewed (elders and young tappers) during field trials in Kalimantan all cited *gaharu/garu* as a paired ritual material used as incense, described locally as *garuman-yan*. As an incense, it is often combined with *sasathin* (resin) and several astringent barks of different trees genera. Participants from the major upstream river corridors *Bahau-Kayan* and Mahakam in East Kalimantan also used "*sekau*" as a catch-all term to denote different types of *gaharu* outcome, including the local names *mu'dung sekau* (*A. malaccensis*), *buaya sekau* (*A. beccariana*), *nyibung sekau, bai sekau, and cabut sekau*. In their hunting, the neighborhood conforms in every respect to the courteous regard for custom. The code of hunting mandates an accepted procedure by which small groupings are

arranged as offerings, while certain taboos and sterilization rituals must be fulfilled before penetration into the forest takes place. The method of hunting or gathering wild agarwood is somewhat similar to checking the museum trees and involves, 'tracing' (spoor & epiphytes), 'testing for infection' (tapping bole), RKP (shallow bark shaving) and then olfaction! Trees are cut down only for confirmed dark oily resin, otherwise viscous strips may be obtained and stem recovers.

In Kalimantan, the boiled leaves of gaharu are used by practitioners to enliven bowels, hypertension and liver. It is beneficial in that the sawdust of gaharu can be employed to make dressing for wound treatment. The smoke of garu-manyan is used in ritual during healing, house-building and field-clearing. It is also used in Kalimantan to play along with ethnics, where the high quality agarwood is regarded as a status symbol. *Aruh Ganal* is also performed as sacrificial rite-offering by Dayak Meratus (South Kalimantan) community in south part of the region. This kind of sacrifice makes gaharu smoke as the main medium and symbolizes thankfulness to God and ancestor.

Agarwood- using communities observed that while their marketing and licensing schemes may have changed, the spiritual value they place on agarwood has remained in situ as an ethical monitoring system for its sustainable exploitation. In light of agarwood resource depletion, some households claimed that from the late 1990s they had been converting accidental tapping into deliberate establishment of an 'agarwood garden' in a mixed agroforestry planting. Line mapping in agarwood hunting is used by many hunters to avoid conflicts and over-harvesting. Such practices also corroborate historical accounts of Dayak ritual sterilization and incense application (e.g., rabun with manyan) as well as regional descriptions of local regulations that protect resin-exuding trees and underline the value high-quality natural resin takes centuries to develop.

The Rejang people of South Sumatra province use agarwood leaves to make a remedy for stomachache and other digestive ailments as well as for shortness of breath. The Dayak community in Central Kalimantan uses agarwood tea to cure malaria and digestive diseases while in East Kalimantan, the resin is used as dressing for burns. The Batak in Indonesia use agarwood smoke for the treatment of respiratory diseases, however in Maluku, *Gyrinops* spp. have a number of uses including as the source material for burying to develop *batik*-like patterns. serves as a local analgesic. In the province of South Sulawesi, you find the Toraja tribe who mix powder from agarwood with honey from the forest to make a tonic. The Anak Dalam tribe in Jambi use the bark of young agarwood trees for breastfeeding.

Agarwood is utilized across various fields, especially in traditional medicine due to its bioactive metabolites. In Indonesia, SNI 7631-2011 outlines quality assessment standards based on factors like color, weight, and aroma, with fragrance being crucial for quality evaluation. Research indicates that the unique aroma of agarwood is linked to diverse bioactive compounds. Ethnobotanical studies show agarwood has traditionally been used for medicinal purposes, including in aromatherapy for treating respiratory issues like cough, asthma, and bronchitis. The soothing effects of burning agarwood fumes have been noted, and its essential oil, rich in sesquiterpenoids like spathulenol, has anti-inflammatory properties. Agarwood compounds also demonstrate antioxidant activity and aid in reducing inflammatory markers such as TNF-α and IL-6. They're beneficial for digestive issues and may help prevent liver damage and improve cardiovascular health. Overall, agarwood is valued not only for its cultural significance but also for its extensive medicinal applications.

The compounds might also play a role in preventing endothelial injury of the myocardium, thus aid cardiovascular and metabolic balance (Hashim *et al*. 2016). In addition to its well-documented religious and cultural applications, agarwood has been used in traditional medicines for the treatment of innumerable diseases (Table 3). The main bioactive compounds identified from agarwood and their pharmacological activities, to provide a scientific rationale for these traditional uses of ethnomedicines.

Table 3. Key bioactive compounds identified in agarwood

Bioactive Compound	Health Benefits	Isolated from	References
2-(2-*phenylethyl) chromone*	Antioxidant, antitumor, anti-inflammatory, antidiabetic	*Aqularia* spp*, Gyrinops* spp.	(Liu *et al*. 2016)
Jinkoh-eremol	Sedative, stress-relieving, used in aromatherapy	*Aquilaria malaccensis*	(Naef 2011, Nakanishi *et al*. 1983)
Kusunol	Antimicrobial, muscle relaxant, used in perfumes	*Aquilaria malaccensis, Aquilaria filaria*	(Naef 2011)

Guaiane-type *sesquiterpenes*	Antibacterial, antifungal	*Aquilaria sinensis, Aquilaria filaria, Aquilaria malaccensis, Aquilaria macrocarpa*	(Gao *et al*. 2019)
Spathulenol	Antioxidant, anticancer, anti-inflammatory	*Aquilaria malaccensis*	(Radzi & Kasim 2020)
Elemol	Analgesic, anti-inflammatory	*Aquilaria* spp.	(Shaian *et al*. 2021)
Benzylacetone	Relaxing effects, mild antidepressant	*Aquilaria malaccensis, Aquilaria sinensis, Gyrinops salicifolia*	(Takamatsu & Ito 2018)
Agarofuran	Neuroprotective, antitumor, antifungal	*Aquilaria malaccensis, Aquilaria sinensis, Aquilaria crassna*	(Yang *et al*. 2014)
Aquilarone A, B, C	Antioxidant, anticancer	*Aquilaria sinensis*	(Ahmaed & Kulkarni 2017)
Gyrinopsin	Antioxidant, antibacterial	*Gyrinops versteegii*	(Hadi *et al*. 2020)
Agarospirol	Relaxing effects, Neuroprotective,	*Aquilaria malaccensis,*	(Kalra & Kaushik 2017)
Caryophyllene oxide	Anticancer, antioxidant, and antimicrobial	*Aquilaria crassna*	(Dahham *et al*. 2015)

Continuity and change in species recognition

Local knowledge of *A. malaccensis* ecology is notably consistent, with colonial reports on bark and leaf recognition being broadly congruent with modern documentation. Concomitantly, socio-economic and scientific progress has resulted in the advent of molecular techniques, where Capelli defines DNA profiling as a technology which is used for determining species; only this time it is these two genera: *Aquilaria* and *Gyrinops* being verified by DNA-based technology instead of traditional suspects (Lee *et al*. 2022). The interaction between field-based heuristics and molecular taxonomy shows "continuity with innovation" in the making of everyday decisions. Several early studies reported the detection of wood with potential to produce agarwood within standing tree trunks using non-invasive technologies such as sound and ultrasound in *A. malaccensis* (summarized by CITES, 2019). Current research is conducted to trace a link of these with indigenous wisdom, particularly how hunters employed natural occurrence such as the existence of pest stem borer and black ant which were utilized as sign for finding out their original agarwood (Karlinasari *et al*. 2017, Putri *et al*. 2017, Karlinasari *et al*. 2015).

In the context of agarwood utilization, there is consistency between traditional knowledge of contemporary communities and classical Indonesian manuscripts and colonial documents. In fact, this traditional knowledge aligns with scientific data. For example, in traditional medicine, agarwood's content is scientifically consistent with its medicinal purposes. The use of agarwood as a gift or tribute to respected individuals is still practiced today. The tradition of burning agarwood remains consistent across traditional knowledge, classical Indonesian manuscripts, and colonial documents, which also mention the practice of burning agarwood in the community. Agarwood as a trade commodity is also recorded in classical Indonesian manuscripts and colonial records. Agarwood trade remains a common practice, and Indonesia is a major source of agarwood. Religious rituals involve agarwood. Agarwood powder is an essential ingredient in incense-burning rituals, temple offerings, and as a fragrance for meditation. Temples in the past were fragrant with the smoke from the agarwood powder. In addition, hermitages with springs and gardens emit mystical energy filled with the fragrance of incense from agarwood powder as told in Mbujangga Manik, Tantu Pangggelaran and Sri Tanjung (Pigeaud 1960, Pigeaud 1924).

However, there are some aspects of society that manuscripts do not mention. The use of agarwood bark for rope, for example, is a knowledge and use commonly known among various ethnic groups in Indonesia, but classical and colonial manuscripts do not mention it. Another aspect that remains unexplained in classical Indonesian and colonial manuscripts is the condition of agarwood hunters. Classical reports or records do not mention the conditions of agarwood hunters. Indonesian manuscripts typically focus more on palace life, medicine, political intrigue, succession of kings, and the arts. They rarely pay attention to the lives of farmers or the fields, rice paddies, and crops.

Agarwood hunters come from communities that inhabit forest areas. They live in groups and far from authority, relying on hunting for their livelihoods. Classical texts such as the Kakawin Siwaratrikalpa by Mpu Tanakung (Teeuw *et al*. 1969) describe the figure of Lubdhaka, who wandered through the forest and hunted for his livelihood. It is strongly suspected that these agarwood hunters held a weak position or status or were outside the societal hierarchy of agrarian kingdoms based on divine law, or sultanates based on divine law. They were not farmers subject to the principles of work discipline, royal hierarchy, and mutual cooperation in clearing forests, clearing forests and cultivating rice, and paying taxes to tax collectors, the king's representatives. Therefore, historical information about agarwood hunters is very limited

Adaptation and resilience of local knowledge and changing human-nature orientations

Historical and political frameworks profoundly condition how agarwood is conceptualized. Data retrieved from the field experience in various producing territories demonstrate that communities are capable of executing ontological work, namely, developing knowledge identities and increasing resilience thorough blending traditional methods with cutting-edge technologies, formulating district-level and inter-island associations, and founding substitute discursive places targeting at reorienting and affirming virtue in local expertise. Such an adaptive suite ensures that production and bargaining power can persist to evolve with changing global market demands (Thompson *et al*. 2022).

Importantly, traditional agarwood grading systems play a central role in this adaptive capacity by functioning not only as quality classification schemes but also as ecological control mechanisms. Because high grades are assigned only to wood containing well-developed resin characterized by specific color, aroma, and density, harvesters are incentivized to selectively fell only trees that meet these criteria. Trees showing immature or low-grade resin are typically left standing to allow further resin development, effectively creating biologically driven fallow periods that reduce unnecessary tree felling and maintain standing *Aquilaria* populations. Moreover, because high economic returns can be obtained from small volumes of high-grade agarwood, traditional grading supports a low-volume, high-value extraction model that limits forest disturbance.

In this way, the inherent concept of sustainability embedded in traditional agarwood knowledge systems is not a making-by-making process aimed at immediate quantitively output (Supriatna & Lenz 2025), but rather a form of adaptive resource governance based on flexibility, selective harvesting, and delayed extraction. This flexibility of innovation allows knowledge systems to adjust to ecological, social, and market conditions while maintaining both livelihoods and forest integrity. At the same time, an epochal shift is transforming human-nature relations. Cosmologies of ecological symbiosis now coexist with more utilitarian and commodified perspective, as communities integrate traditional practices with modern approaches to remain economically viable while preserving cultural and ecological values a form of cultural resilience essential for sustaining indigenous knowledge in a globalized economy (Asrawijayam 2024).

Market regulation, spiritual value, and conservation implications

Much of the trust-based patron-client exchange has been replaced by modern market mechanisms and rules, influencing motives and information flows. The relevance of agarwood as an article of cultural value in local settings, and the influence it has had on practices driving demand for and supply of the products continue (Soehartono & Newton 2001). The combination of interviews, colonial sources and Nusantara manuscripts yields policy-relevant insights. Selective and sustainable harvesting methods are reported from the old literature which may be helpful to modern conservation efforts. Further, new interviews indicate additional regulatory and market challenges that policy should consider in shaping (Zouraris *et al*. 2025).

Implications for policy and management as Indicators and interventions

The adaptive patterns documented in Kutai Kartanegara—species diversification, product differentiation, and selective uptake of inoculation technologies—provide concrete guidance for agarwood policy and management. Rather than attempting to standardize or replace traditional knowledge systems, policy frameworks should recognize and strengthen these locally proven adaptive strategies. Regulations that restrict agarwood cultivation to a single species or a single technological model risk undermining the very resilience that enables communities to sustain production under ecological and market uncertainty.

Agarwood governance should therefor prioritize policies that protect and enable local experimentation, including diversified agroforestry systems, community-led inoculation trials, and adaptive harvesting practices. Formal management plans and certification schemes should document not only production outcomes but also the processes by which communities adapt to environmental change, market volatility, and regulatory shifts. Support for intergenerational knowledge transmission and

intercommunity exchange is equally critical, as these mechanisms have been shown to sustain adaptive capacity across successive cycles of change.

By aligning national agarwood regulations with the adaptive strategies already practiced at the community level, policy can move from a control-oriented model toward one that stewardship, ecological resilience, and long-term sustainability of agarwood-producing landscapes.

Conclusion

This study concludes that an innovative interdisciplinary "change and sustainability" model, which successfully synthesizes the deep cultural interconnectedness and adaptive resilience of traditional agarwood knowledge systems, offers a practical application for sustainable management of the agarwood resource. The results demonstrate that agarwood utilization cannot be understood solely through a static conservation framework; instead, it requires recognition of a dynamic knowledge system that continually evolves through intergenerational transmission, local innovation, and responsive adaptation to the ecological and socio-economic pressures faced by local communities living around the forest. The model's unique contribution lies in its ability to reveal how traditional ecological knowledge functions not as a relic of the past, but as a living, adaptive system that balances cultural continuity with the innovation necessary for survival in a changing environment. This interdisciplinary approach bridges anthropology, ecology, and sustainability science and technology to demonstrate that indigenous and local communities retain modern adaptive capacities that are crucial for long-term resource management. These findings strongly suggest that sustainability policies must shift from conservation approaches that freeze traditional practices in time, toward dynamic frameworks that actively support and enhance communities' adaptive capacities. Sustainability policies are crucial: they must facilitate intergenerational knowledge transfer, encourage locally driven innovation, and recognize that the vitality of traditional knowledge systems depends on their ability to evolve rather than remain static. The researchers strongly recommend integrating cultural ecology policies that formally embed local knowledge systems into national conservation frameworks through institutional mechanisms such as community-based co-management arrangements, certification systems for ethically and sustainably sourced agarwood, and educational programs that maintain ecological integrity and cultural vitality. This integrated approach offers a more resilient and culturally appropriate pathway to sustainable agarwood management that respects both environmental conservation and the living traditions of the communities that have managed this resource for generations.

Declarations

List of abbreviations: Not available

Ethics approval and consent to participate: Not applicable

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