Working Paper

Gaharu (eaglewood) Domestication:
Biotechnology, markets and agroforestry optios

Bambang Soeharto, Suseno Budidarsono, Meine van Noordwijk

World Agroforestry Centre

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Bambang Soeharto was trained as a forester and completed his PhD in 2011 on the topic 'Value of water and benefit for communities and hydropower in Way Besai, Sumberjaya sub-district, Lampung Barat district, Lampung province'. At the time of writing the basic part of this study he was a consultant at the World Agroforestry Centre. He worked on various aspects of business development of forest and agroforestry products in Indonesia. He passed away in 2015.

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Abstract

Agarwood, produced by trees of the genus *Aquilaria* in response to wounding and infection by fungi such as *Fusarium*, has a long history as one of the most valuable non-timber forest products in SE Asia, providing income to forest-dependent people. With the emergence of controlled infection with *Fusarium* concoctions of *Aquilaria* trees planted in monocultural plantations or as understory on tree crop plantations or agroforests, considerable shifts in the location of production, in the balance of supply and demand, and hence in the price can be expected. We provide an overview of current use, grading and demand, as well as current supply, based on literature and trade data. Description of the current state of biotechnology and its main actors, is followed by an estimate of the way supply from domesticated sources will undercut current collection of agarwood as forest product. Between 2010 and 2020 domesticated sources are expected to fully replace forest collection, with a fall in price by a factor of about 2. Early adopters among the rubber (and other) agroforest owners in the relevant agro-ecological domain are likely to benefit substantially, while later adopters will still get a resource competitive to rubber trees per unit space. Active spreading of knowledge on the agarwood biotechnology is in the interest of the managers of diverse rubber agroforests.

Keywords:

Adoption, Ex ante impact, Indonesia, Fusarium, Aquilaria, Thymelaeaceae

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We thank our ICRAF colleague Endri Martini for providing detailed comments on the final text.

Contents

List of Tables

List of Figures

List of abbreviations and acronyms

ASGARIN	(*Asosiasi Pengusaha Eksportir Gaharu Indonesia*/ Association of Indonesian Gaharu [Agarwood] Exporters),
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
IUCN	International Union for Conservation of Nature

1. Introduction: Domestication users and losers

The forests of Southeast Asia have provided goods for international trade since two-thousand year ago (if not before), initially within Asia (with China followed by the Middle East as markets), later including Europe and the America's. Most forest resources have experienced ups and downs, linked to changes on the supply and the demand side of the equation. When supply scarcity drove up prices, people were motivated and rewarded to go deeper into the forest and harvest from previously underexploited resources, as long as these were still available. The end of this is now in sight, with hardly any forest out of reach for forest resources of high value relative to the transport costs. Apart from harvests from more remote places, high prices also induced innovation in ways to stimulate the reproduction of the biological resource, in forms of 'domestication'. A number of forest products have been (nearly) exterminated before domestication had success, in others the process started early enough and proved to be successful. Domesticated forest resources may first of all be utilized within farmer-managed forms of 'agroforest', with clear rules for local resource access and opportunities for exclusion of outsiders and protection from theft. When domestication was technically successful, however, the scarcity problem was resolved, prices came down and the drive for further innovation and domestication disappeared. The early adopters and innovators in domestication might have gained in the process, others will have lost an opportunity for deriving value from forests and will instead have gained an additional option for their agroforests, but not a very profitable one. When we look at the domestication process from the angle of 'users and losers', we may come to a more nuanced view on the overall economic gains and poverty effects of the process. Usually, such perspective is only formed in hindsight, while the *ex ante* impact assessments of the domestication emphasize the gains and benefits to be expected only.

International trade in gaharu involves at least 18 countries and hundreds of tonnes worth millions of US dollars annually (Wyn and Anak 2010), with growing affluence of gaharu-consuming markets leading to increasing market demand. Active research has been aimed at developing biotechnology (domestication) options for agarwood (eaglewood), the product of the wounding response of a number of tree species (in the genera *Aquilaria* and *Gyrinops* with a wide array of chemical constituents; Chen et al 2012*)*. It has been the basis for an age-old trade to China and the Middle East from the rain forests of SE Asia. As only about 10% of the *Aquilaria* trees in the forest may contain gaharu (Gibson 1977), the existing harvest technique based on cutting trees and hoping they contain gaharu is destructive (Soehartono and Newton 2002). Considerable skill is needed in finding and recognizing high quality agarwood. Jensen and Meilby (2008) documented substantial differences in skill and success rate among gaharu collectors in Pas PDR.

In 1995, *Aquilaria malaccensis* was included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In 2004, all remaining species of the Genus Aquilaria, as well as the related Genus Gyrinops, were listed in CITES Appendix II at the 14th

Conference of the Parties to CITES[1]. However, Wyn and Anak (2010) discussed why there has only been partial implementation of CITES controls due to the numerous complexities of the nature of the gaharu trade: gaharu is not a uniform commodity, produced by a wide variety of tree taxa and with highly variable chemical composition. The absence of standard grading rules or species identification procedures makes effective regulation and monitoring difficult, while small quantities of top grade gaharu are easy to conceal. The International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2016) lists two species as critically endangered (*A. crassna* and *A. rostrata*), and seven others as vulnerable (*A. banaensae, A. beccariana, A. cumingiana, A. hirta, A. malaccensis, A. microcarpa,* and *A. sinensis*).

According to Donovan and Puri (2004) the Penan people living in Malaysia's rainforests recognize the complex ecology of resin formation involving two, or maybe three, living organisms — the tree, one or more fungi, and possibly an insect intermediary. According to these authors attempts at cultivating the valuable aromatic resin, gaharu, have been uneven at best and they expected that gaharu will largely remain a natural forest product, increasingly under threat as the trees are overexploited and forest is cleared. As gaharu harvested from the wild is now protected by the international CITES convention, it is important that the cultivated product can be chemically distinguished from the wild one. According to Espinosa et al. (2014) an initial test for such distinction based on the full spectrum of oleochemicals has an 85% accuracy: the cultivated product is very similar with the wild one, but can be cleared for international trade as long as it maintains a different signature.

Such distinction may not apply to results of further biotechnological progress. Liu *et al.* (2013) reported significant progress on the technique to induce gaharu formation, where the initial agarwood-inducing methods produced poor-quality agarwood at low yield. Their 'whole-tree agarwood-inducing technique (Agar-Wit)' uses ten different agarwood inducers injected into the xylem of *Aquilaria* trees through transfusion sets. Due to water transportation, the inducers are transported to the whole body of the tree, thus forming an overall wound in the tree, and as a result, agarwood is formed throughout the entire tree from the transfusion point in the trunk to the roots and branches of the whole tree. They reported an agarwood yield per tree of 2.4 – 5.9 kg, with a quality similar to that of wild agarwood.

In view of this significant progress, the current document is a partially updated version of an *ex ante* impact appraisal made in 2006. We have not updated data on use (and market demand) and supply (and technical innovations), but entered the increased success of the biotechnology in a quantitative prediction of winners and losers.

[1] CITES, 2004. Convention on International Trade in Endangered Species of Wild Fauna and Flora Appendices I, II, and III. UNEP-WCMC. *Aquilaria* protection involves all species and all parts and derivatives except: a) seeds and pollen; b) seedling or tissue cultures obtained *in vitro*, in solid or liquid media, transported in sterile containers; c) fruits; d) leaves; e) exhausted agarwood powder, including compressed powder in all shapes; and f) finished products packaged and ready for retail trade, this exemption does not apply to beads, prayer beads and carvings. http://www.cites.org/eng/app/appendices.php

2. Uses and grading system

2.1 Agarwood

For many years trees of *Aquilaria* and *Gyrinops* spp. have been harvested from the wild for the purpose of collecting gaharu in their resin-impregnated heartwood that is fragrant and highly valuable (Yamada 1995; Chakrabarty et al 1994; Roemantyo 1992; Beniwal 1989). There are many names for this resinous wood, including agar, agarwood, aloeswood, eaglewood, gaharu and kalamabak. This wood is in high demand for medicine, incense and perfumes across Asia and the Middle East. The classification (grading) of agarwood and therefore its value, don't depend on the tree species involved, but on the fragrance of the woodchips, or in the case of extracted oil, on the purity. The country of origin is also an important factor that determines the value of agarwood.

The genera *Aquilaria* and *Gyrinops* in the family of *Thymelaeaceae*, contain several species in the tropical forests in Asia (CIFOR 1996; Burkill 1966; Ding Hou 1960). *Aquilaria malaccensis* is the best known among 15 species in the Indomalesian genus *Aquilaria* (family *Thymelaeaceae*) 8 of which are confirmed sources of agarwood (Mabberley 1997; Chen et al 2012). It is a large evergreen tree growing over 15-30 m tall and 1.5-2.5 m in diameter and has white flower (Chakrabarty et al 1994). The species has a wide distribution, being found in Bangladesh, India, Indonesia, Malaysia, Myanmar, The Philippines, Singapore and Thailand.

Historically the trade of agarwood (Gaharu) has been going on since the 1^{st}-15 centuries A.D (Giano 1992). A number of authors reported that China since 3^{rd} century regularly imported agarwood from the Malay Peninsula and elsewhere (Giano 1992; Wang 1958; Burkill 1935). India and the neighbouring countries have also long been recorded as one of the biggest producer of agarwood (Chakrabarty et al 1994 and Burkill 1935).

The historical movement of harvest and trade sources for the global agarwood market (all species) has moved progressively eastwards from India, through mainland Southeast Asia, to Sumatra and Borneo, and since 1997 has been characterized by large sources of supply from the island of New Guinea. Initially this took the form of *Aquilaria filaria* from Papua (formerly Irian Jaya) but Papua New Guinea has begun reporting agarwood export sourced from *Gyrinops ledermannii* to Singapore since 1999. UNEP-WCMC CITES data show that Indonesia and Malaysia remain the two most important suppliers of agarwood designated as being from *A. malaccensis* to the international market, reporting exports of 1,043 t and 2,420 t respectively between 1995 and 2001. Singapore's role as a re-exporter of *A. malaccensis* (mostly in the form of chips, powder/dust and timber) from these two Countries remains paramount in the overall global trade dynamic, with reported re-exports from Singapore totalling 1,448 t between 1995 and 2001. Thailand also reported exports of *A. malaccensis* in 1997. Hong Kong S.A.R and India also play important roles as re-exporting and consuming States. Taiwan (province of China) is the most important final destination market for *A. malaccensis* and its Customs data reveal that it is also a substantial importer of agarwood from other *Aquilaria* spp. Other significant final destination markets include United Arab Emirates (UAE), Saudi Arabia and Japan.

2.2 Uses of agarwood

Agarwood has three principal uses: medicine, perfume and incense. Smaller quantities are used for other purposes, such as carvings. These use are described in more detail below

2.2.1 Use in medicine

Agarwood has been used for medicinal purposes for thousands of year and continues to be used in Ayurvedic, Tibetan and traditional East Asian medicine (Chakrabarty et al 1994; Fratkin 1994). The Sahih Muslim, which dates back to approximately the eight century, refers to the use of agarwood for the treatment of pleurisy and its use is referenced in the Ayurvedic medicinal text the Susruta Samhita. Agarwood is prescribed in traditional East Asian medicine to promote the flow of qi, relieve pain, arrest vomiting by warming the stomach and to relieve asthma (Anton, 1995a). High-grade agarwood powder is prescribed in Chinese medicine (Yaacob 1999) and is also used in the production of pharmaceutical tinctures. Burkill (1966) reported that Malaysians used agarwood mixed with coconut oil as a liniment and also in a boiled concoction to treat rheumatism and other body pain. Bull (1930), cited in Chakrabarty et al 1994) notes agarwood's use as a complex ointment for smallpox and for various abdominal complains. Agarwood is also prescribed for dropsy as a carminative, a stimulant, for heart palpitations and as a tonic taken particularly during pregnancy, after childbirth and for diseases of female genital organs (Chakrabarty et al 1994).

2.2.2 Use in incense

Agarwood incense is burned to produce a pleasant aroma, its use ranging from a general perfume to an element of important religious occasions. Irregular chunks of agarwood, usually a few cm long and weighing 10-200 g, may be cut or broken into smaller pieces and then burned, usually in a specially made incense burned. Agarwood powder and dust cannot be burned directly in incense holders, but can be used to make incense sticks or coils for indoor fragrance and are used for religious purposes by Muslims, Buddhists and Hindus (Yaacob 1999).

Taiwanese consumers purchase agarwood for manufacture of incense sticks, which are use in prayers during many traditional festivals and ceremonies to bring safety and good luck. Both Indians and Chinese have used agarwood as an essential ingredient of incense sticks in the past, but in the present day incense sticks generally do not contain agarwood, although Indian trader report that high-quality Indian incense sticks destined for export may have a drop of agarwood oil added to them (Chakrabarty et al 1994).

Japanese incense products are very different, with most of the highest-grade product made using natural raw materials which ground agarwood extracts combined with other ingredients such as sandalwood an benzoic and then carefully moulded and baked. Pure agarwood is also burned as incense in Japan. The user breaks pieces off and burns small pieces as required, hence large sections of wood will last several years (Heuveling van Beek and Phillips 1999). In Japan, a revival in the ancient art of *Koh doh*, the incense ceremony, has revitalised interest in agarwood (Katz 1996).

In Malaysia, Muslim burn agarwood splinters or chips to produce incense during special religious occasions, particularly at gatherings and agarwood incense has been recorded in use there during Ramadan prayers (Chakrabarty et al 1994).

2.2.3 Use in perfume

The use of agarwood for perfumery extends back several thousands of year and is referenced, for example, in the Old Testament several times using the term ‘aloes’. Both agarwood smoke and oil are customarily used as perfume in the Middle East. In India, various grades of agarwood are stilled separately before blending to produce a final ‘attar oil’. Minyak attar is a water- based perfume containing agarwood oil (Figure 1), which is traditionally used by Muslims to lace prayer clothes (Yaacob 1999).

Figure 1. Agarwood oil (photo: Bambang Soeharto)

Agarwood perfumes are seldom pure agarwood oil, but instead use an alcoholic or non-alcoholic carrier, such as sandalwood oil. According to Heuveling van Beek and Philips (1999) the cheapest agarwood perfumes are either synthetic or a blend of oils, each with different qualities and fragrances. Although there are several commercially available synthetic agarwood fragrance compounds, they can produce only low-quality agarwood fragrances, owing to the chemical structure of natural oil.

Agarwood essences have recently been used as a fragrance in soaps and shampoos. Agarwood is said to have been highly prized by European perfumers in the mid-1990s (cited in Chakrabarty et al 1994).

2.2.4 Other Use

Grated agarwood has been used in Malaysia for cosmetic purposes, particularly during sickness and after childbirth (Burkill 1966). The use of agarwood bark as a writing material has also been documented extensively and agarwood in used for chronicles of important and sacred religious books. Use as a substitute for paper is also know from the mountaineers of Annam (Vietnam) and from China (Chakrabarty et al 1994).

Although it may be possible to use healthy Aquilaria wood to make simple ornamental boxes, this wood is typically too light and fibrous (rather like balsa wood) to be suitable for furniture, construction or even carving. Some forester in India have suggested using Aquilaria wood for constructing tea-boxes (Chakrabarty et al 1994). Aquilaria bark was reportedly used for this purpose during the nineteenth century (Heuveling van Beek and Phillips 1999). There is a considerable number of craft shops offering religious agarwood sculptures, usually Buddhist figures. Although a proportion of immature agarwood is used in this trade, most statues are not made with agarwood, owing to its soft and flaky properties, which make it unsuitable for carving. Instead, tropical

hardwood are treated to resemble agarwood. The wood is blackened by injecting oil or tar into tree trunks and may also be impregnated with agarwood perfume (Heuveling van Beek and Phillips 1999).

As with carvings, most agarwood rosary and ‘worry beads’ offered for sale are fake, owing to the cost of shaping and drilling perfectly round beads of authentic agarwood. Instead, other dark woods may be submerged in agarwood oil for several weeks until the fragrance of agarwood has been absorbed and these are than used in place of agarwood.

Agarwood is used as an aromatic ingredient of *Chu-yeh Ching* and *Vo Ka Py* wine in Taiwan (Traffic East Asia-Taipeh, in litt to Traffic International, May 1999). Agarwood powder in known to be sprinkled on clothes and skin as an insect repellant effective against fleas and lice (Heuveling van Beek and Phillips 1999).

2.3 Commodity classification/grading

Agarwood is not a uniform product, but instead possesses different characteristics. It is classified according to various grading systems that differ according to the product in trade and country in which trade is taking place. The grade (and hence value) of agarwood and agarwood derivatives such as oil is determined by a complex set of factors including: country of origin, fragrance strength and longevity, wood density, product purity, resin content, colour, and size of the form traded.

The type and number of agarwood grades used within a given country may vary widely. One large dealer in Singapore, for example, usually offers flakes or chips from five or six countries, the agarwood from each country divided into three to five grades (Heuveling van Beek and Phillips 1999). The chemical components of different grades have been studied (Ishihara et al 1991, cited in Ng et al 1997) suggested that the chemical profile of agarwood varies according to species. Whether or not is this case, it is primarily the country of origin and quality of wood and not necessarily the species from which agarwood is derivate, that is of greatest importance to consumers and hence traders.

One Dubai-based agarwood dealer interviewed in Mumbai considered that the best of agarwood was obtained (assuming supplies existed) from the following range states, in order of decreasing value: Bhutan, India, Myamar, Lao PDR, Cambodia, Vietnam and Indonesia. A similar order of preference was given by the largest agarwood-trading company in India with respect to agarwood destined for the Middle Eastern market, although the company reported agarwood from Assam to be most sought after (Heuveling van Beek and Phillips, 1999). Ng et al (1997) reported that the highest-quality agarwood is that obtained from *Aguilaria bailloni* (Cambodia), *A. crassna* (Thailand), *A. grandiflora* (Hainan, China) and *A. agallocha*, which they considered to be a variant of *A. malaccensis* found in Bangladesh, Bhutan, Myanmar and India, in Assam and the north-eastern border districts. Consumers and traders In Taiwan believe that the highest quality of agarwood are sourced from Sumatra, Borneo and from some other islands in the Malay Archipelago (Traffic East Asia-Taipei in litt to Traffic International, 2 May 2000).

The consumers observe in different countries have different priorities for assessing the quality of agarwood, which relate to its intended use. Consumers from the Middle East consider fragrance to be

the most important quality and in India a significant quality of agarwood oil is used for perfumery, hence odour quality is of prime importance. Consumers from Taiwan buy substantial quantities of agarwood for medical purposes and in such cases it is not the fragrance of agarwood but the quantity and composition of resinous material in the wood that is of greatest importance (Heuveling van Beek and Phillips 1999).

According to Heuveling van Beek and Phillips (1999), agarwood oil is graded based on the quality of raw materials, the method of distillation and the skill used in processing. It is said to be now virtually impossible to find pure agarwood oil (although a supposedly pure sample was received by TRP from a large international agarwood-trading group in Dubai). Traders have quoted prices for pure agarwood oil as high as USD 30,000/kg, such oil only being made to order. Grade-two oil cost approximately USD 15,000/kg, but generally oil prices are between USD 5000/kg and USD 10,000/kg. However, cheaper oils, adulterated with perhaps a mixture of sandalwood and sesame seed oil, can be bought for a few hundred dollars per kilograms. Few traders nowadays, if any, can assess oil quality or purity and it is unlikely that there is much consistency between oil batches. Only one large agarwood-trading company appears to be capable of testing oil purity using gas chromatography and high performance liquid chromatography.

Many traders (country) has its own agarwood grading system, there is no record of a systematic explanation of these systems.

2.3.1 Indonesia

In the market gaharu product are available in the form of fragments of wood, chips, oil and powder and some times in the form of a permeated liquid. The wood and chips vary in colour from light brown to dark brown or nearly black. The darker the product the higher the resin content and the quality. In the case of powder, the colour is normally light brown to medium brown. Although in reality it is difficult to differentiate source species among the products.

Based on the information from ASGARIN (*Asosiasi Pengusaha Eksportir Gaharu Indonesia*/ Association of Indonesian Gaharu [Agarwood] Exporters), gaharu graded into two classes, in local market (as may also in International markets) the quality of the product is graded into seven to eight classes depending on the region, the classification was made according to the resin content (Table 1).

Table 1. Grading classification of gaharu at the domestic and international market, in the forms of chips

Grade	Domestic market grading	International market grading	Main importer
Grade I (gubal gaharu)	Double super	Double super	Midle East (Timur Tengah)
	Super	Super A	
	Super AB: Kacang A/ Teri A =Teri Sinking	Super B	
	Super AB: kacang B/ Teri B =Teri Floating	Kacang Sinking = Teri A	
		Kacang Floating = Teri B	
Grade II (keme-dangan)	Kemedangan: Teri Floating/ Teri C	Kemedangan A	South/ East Asia
	Kemedangan: Kemedangan C (white)	Kemedangan B	

Grade	Domestic market grading	International market grading	Main importer
	Dust (processed)	Kemedangan C	
		TG. C (BC)	
		Kemedangan C (white)	
		Dust (Processed)	

Source: ASGARIN 2005

The grade classifications vary slightly with locality and also from one middlemen (who typically link collectors with trader) or collector to another. Quality indicators of grade in Indonesia are shown in Table 2.

Table 2. Gaharu Grade and Quality indicators in Indonesia

Grade	Quality indicator
Super A	Very black, heavy witch much resin
Super B	Black, heavy with moderate amount of resin
Super C	Fairly black, heavy with moderate amounts of resin
Sabak	Less black, moderately heavy with less resin
Kemedangan bungkus	Very brown, less resin
Teri padat	Debris of super A and B
Teri timbul	Debris of super C and Sabak
Teri laying	Debris of kemedangan bungkus
Kemedangan Kropos	Yellowish brown, light and very little resin

The price of gaharu varies according to the quality, place of origin and time of collection. The higher quality has higher value. The gaharu price in Samarinda, Kalimantan Timur, 2003 as shown in Table 3.

Table 3. The gaharu price in Samarinda, Kalimantan Timur 2003 (with an exchange rate of approximately Rp 9.000/ $)

No	Grade	Prices (Rp/kg)
1	Super King	11.000.000
	Super	8.000.000
	Super AB	6.000.000
2	Tanggung	4.500.000
3	Kacangan A	2.500.000
	Kacangan B	2.000.000
	Kacangan C	1.500.000
4	Teri A	1.000.000
	Teri B	750.000
	Teri C	500.000
	Teri kulit A	300.000
	Teri kulit B	200.000
5	Kemedangan A	30.000
	Kemedangan B	25.000
	Kemedangan C	20.000
6	Suloan	10.000

Source: Yusliansyah et al 2003

2.3.2 Taiwan

Taiwan have five criteria on grading system: the amount of resin content and resin distribution, colour and scent, causes of formation, age and location in a three, size and form, source and scarceness (//www.cites.org/common/com/pc/15/X-pc15-07-inf.pdf.May, 29, 2006).

- *The amount of resin content and distribution*

  The higher resin content an agarwood pieces has, the higher the price. High resin content allows wood pieces to produce a purer or higher-level scent as well as provide greater therapeutic effect. The most common method of grading is to place agarwood pieces into water and then the pieces are classified into three basic grades: sinking, half-sinking (or half-floating) and floating. Sinking pieces (the literal meaning of the Chinese name for agarwood, Chen H'siang is "sinking fragrance") are top grade and the rest are divided into different grades base on diverse standard, including the pattern of resin distribution in each pieces. Higher resin content also gives an agarwood pieces more weight than other in similar size. Many traders also stated that agarwood grading is very objective, meaning that it takes years of experience to learn to distinguish accurately between different types and grades of agarwood. However, One trading company base in Korea, but with a long experience of dealing with the Taiwanese market, believes that there is substantial amounts of fake or adulterated Ch'en Hsiang currently available in Taiwan's consumer market, and that the Ch'en Hsiang classification is mis-applied to agarwood of lesser quality.

- *Colour and scent*

  A number of trades who specialize in high-grade agarwood indicate that agarwood from different countries/island of origin contains distinctive resin coloration. It is said that the colour of resin that an agarwood piece holds is the main factor determining its scent when it is burnt. The colour mentioned include: green, dark green, yellow, golden, red (purple), black, brown and white. The darker an agarwood piece, the higher the resin content and therefore the higher grade (i.e. sinking in water plus dark colour; Barden et al 2000; Song 2002). In the general retail market, most trader (retailer) explained that scent is the major factor influencing a consumer's decision. In general, agarwood materials and products producing in softer scent are considered as higher grade, are more popular and are sold at higher prices in Taiwan than those producing a more intense scent. There are no systematic indicators that demonstrate a uniform relation between colour, scent, grading and pricing.

- *Causes of formation, age and location in tree*

  Agarwood raw materials extracted from dead tree buried in the ground or from a swamp are generally considered more 'mature' material, which can contribute to higher grading and higher prices than agarwood extracted from a standing tree. When comparing agarwood taken different parts of the same tree, agarwood from the roots is considered higher grade than agarwood from higher parts of a tree.

- *Size and form*

  For agarwood pieces, when two pieces are at a similar level of grade according to other characteristics, the value of the large piece could be many times more than the ratio between the pieces respective weight. Agarwood pieces that have natural shapes of aesthetic value are usually picked out by traders to be sold at higher prices to agarwood (art) collectors.

- *Source and scarceness*

  Agarwood items from sources known to have increasingly scarce supplies, such as those from Vietnam are sold at much higher price than other of similar grade.

2.3.3 Singapore

Traders in Singapore revealed that knowledge of valuation and grading is extremely complex and a good buyer is said to be able simply to smell the wood and determine its country and province of origin and grade. Other need to burn portions of the product before making such an assessment. Traders separate out highly resinous products or products with particularly special fragrances to offer to buyers willing to pay high prices (Heuveling van Beek and Phillips 1999).

The practice of grading, the placing the wood in water to separate ‘sunken wood’ from floating woods or flakes, to meet the requirements of their customers from Taiwan. Prices for sunken wood in Singapore are approximately USD 400-500/kg, Sumatra sunken wood sells for USD 420/kg in Singapore, sunken wood from Sabah being slightly more expensive at USD 480-500/kg. Traders generally felt that agarwood from Cambodia and Lao PDR was best, selling at USD 2000-3000/kg for wood segments. Some Middle Eastern clients preferred wood from Myanmar, however which has a distinct odour profile. Samples of agarwood oil distilled in Malaysia can be bought for USD 8450/kg and superior oil from Cambodia was valued at USD 14.485/kg (Heuveling van Beek and Phillips 1999).

2.3.4 Japan

Japan does nor harbour for any agarwood-producing species, and has therefore always relied upon sources in Southeast (and possibly South) Asia for its supply. Historically, Indochina (primary Vietnam) and Indonesia (primarily the island of Borneo, which includes Brunei Darussalam, Indonesia and Malaysia) have been the two most important sources of supply to Japan.

In *koh-doh*, the fragrance of agarwood is classified by the terminology *go-mi rikkoku* (literally “six countries, five flavours”, which was systematized during the Muromachi Period. This system classified scent into one or six catagories according to its place of production or export, and then further distinguished them according to five “flavour” or “tastes”. The six geographic sources were *Kyara, Rakoku, Manaban, Sasora and Sumatora*; while the five flavours were sweet (resembling the smell of honey or concentrated sugar), sour (resembling the smell of plums or other acidic foods), hot (resembling the smell of red pepper when put in fire), salty (resembling the smell of towel after wiping perspiration from the brow, or the lingering smell of ocean water when seaweed is dried over a fire), and bitter (resembles the smell of herbal medicine when it is mixed or boiled) (Morita 1992). Human characteristics were also often ascribe to the various classifications. Detailed rikkoku

classifications differ between *koh-doh* school, some of which include all types of agarwood, sandalwood and other natural aromatic ingredients.

The classification system of the classical *go-mi rikkoku*, develop by literati and connoisseurs appointed by Shogun Ashikaga Yoshimasa in the 16th Century:

1. *Kyara* — A name originating from the Sanskrit kara, meaning "black". The highest quality variety of agarwood and prossessing all five componen flavours (as listed below), kyara is prized for its noble and elegant scent, like an aristocrst in its elegance and gracefulness.
2. *Rakoku* — A sharp and pungent smell similar to sandalwood and possessing bitter, salty and hot flavours, reminiscent of warrior. Soerced from Thailand.
3. *Manaban* — With a great variety of scents and rich in resin ingredients and possessing mostly sweet flavour, coarse and unrefined, like a peasant. Believed to be sourced from the east (Malabar) coast of India and from Indo-Malaysia.
4. *Manaka* — Among the scented woods, this type has a rather shallow scent and is not strongly related to any of the five flavours, light and changeable like a women's feeling. Sourced from Malacca (Malaysia).
5. *Sasora* — A quiet scent with a light and faint flavour, with good quality sasora mistaken for kyara, especially when it first begin to burn, reminiscent of a monk. Believed to be sourced from western India, but this in uncertain.
6. *Sumatora* — Rich in resin ingredient and sour at the beginning and end, sometimes easily mistaken for kyara, reminiscent of something distasteful and ill-bred, like a servant in his master's clothing. Sourced in Sumatra (Indonesia).

2.4 Agarwood/gaharu trade

2.4.1 Countries exporting *Aquilaria* spp.

CITES annual report data indicate that Indonesia and Malaysia are the main sources of *Aquilaria malaccensis* in trade, with total CITES-reported export of approximately 923 ton and 341 ton, respectively from 1995 to 1997. Heuveling van Beek and Phillips (1999), similarly identify these two countries as the primary suppliers of agarwood to international markets is further confirmed by Customs data from Taiwan, which show imports of nearly 3000 ton of agarwood (species unknown) originating from Indonesia between 1993 and 1998.

As noted above, Malaysia's share of the trade may be larger than indicated by CITES data: close to 500 ton of agarwood were recorded in CITES permit data as exported from Serawak alone in 1988, significantly exceeding Malaysia's total CITES-reported trade in the product for the previous three years, which only reflects export from Peninsular Malaysia.

Table 4. *Aquilaria malaccensis* import and export (kg) from range States

Range state	Year	Import reported from range states	Export reported by range states
Indonesia	1995	500	323,577
	1996	214,095	293,593
	1997	0	305,483
Peninsular Malaysia	1995	116,581	90,478
	1996	157,713	163,107
	1997	90,830	87,230
Thailand	1997	216	244

Source: CITES annual report data compiled by WCMC and TRAFFIC International

Report data in *Aquilaria malaccensis* are summarized in Figure 2. Thus far, CITES annual reporting for trade in *A. malaccensis* has been inconsistent and in the case of many consumer countries non existent. The Accuracy of CITES annual report data for trade in *A. malaccensis* is compromised not only by lax reporting, but also by the difficulty in identifying agarwood to special level. More than one agarwood-producing species of the genus Aquilaria occurs and harvested in key *A. malaccensis* range states.

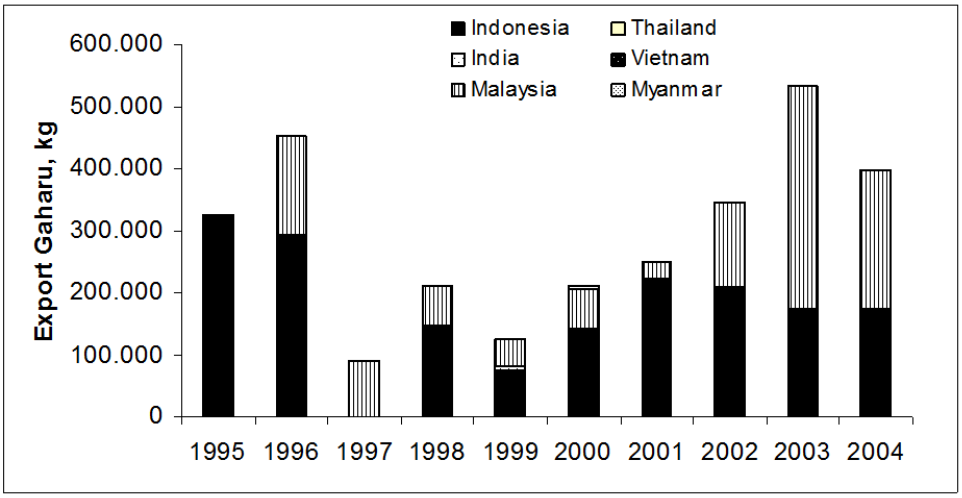

Figure 2. Export gaharu from countries range 1995 to 2004

Sources: UNEP-WCMC CITES Trade Data base (to process), 2006; Indonesia, Source data 2000-2004, ASGARIN 2005

CITES annual report data show a total net trade of agarwood in raw and semi processed form (i.e. timber, chips and powder) of over 7402 ton from 1995 to 2003. Agarwood trade shown that Indonesia is the biggest agarwood exported 63.73%, and followed by Malaysia, 35.63%.

2.4.2 Countries importing *Aquilaria* spp.

The top three country in terms of economic value or agarwood imported to Taiwan 1999-2003 over the same period were Indonesia (56.86%), Vietnam (37.52 %) and Malaysia (4.72 %). Comparing the two major sources, agarwood imported from Indonesia is nearly four times of that from Vietnam in quantity, yet only 1.5 times in value. The value of agarwood per kilogramme from Vietnam is about 2.5 times that from Indonesia.

The average declared value per kg from 1999-2003 were divided into two periods, trending from higher value in 1999-2000 to a lower value from 2001-2003. A part from the extremely high-value agarwood imported from Hongkong to Taiwan under the medicinal agarwood category in 1999, agarwood from Vietnam has the highest average value per kilogramme (USD25/kg) of all categories among all regular source countries, followed by Malaysia (USD 19/kg) and Indonesia (USD10/kg), see Table 5.

Table 5. Agarwood imported to Taiwan 1999-2003 by quantity and declared value (in brackets)

Country	1999	2000	2001	2002	2003	Total	%
Australia	3089 (896)	0	0	0	0	3089 (896)	0.10
Hongkong	360 (6126)	0	0	0	0	360 (6126)	0.01
India	0	14525 (4375)	0	250 (3425)	0	14775 (7800)	0.47
Indonesia	588 759 (9150802)	500440 (8279512)	457985 (1554085)	283852 (1224095)	404576 (1820780)	2235612 (22029274)	70.69 (56.86)
Israel	2123 (12519)	0	0	0	0	2123 (12519)	0.07 (0.03)
Laos	0	14865 (7769)	0	260 (1712)	360 (2391)	15485 (11872)	0.49 (0.03)
China	370 (3176)	1 907 (1926)	0	0	18	2 295 (5160)	0.49 (0.03)
Malaysia	1070 (12972)	22996 (1554 876)	46663 (119049)	10728 (24080)	15402 (120062)	96859 (1831039)	3.06 (4.72)
Myanmar	0	3801 (559)	0	0	0	3801 (559)	0.12 (0.01)
Singapore	4209 (52138)	2600 (21003)	1617 (11350)	1857 (8073)	0	10283 (92564)	0.33 (0.24)
Thailand	26831 (7670)	54255 (18889)	20755 (94626)	27510 (13335)	71425 (20558)	200776 (155078)	6.35 (0.40)
Vietnam	222391 (10262963)	101517 (3901404)	62517 (128501)	33110 (157762)	157490 (84288)	577025 (14534918)	18.24 (37.52)
Total	849202 (19564352)	716906 (13790313)	589537 (1907611)	357567 (1432 482)	629271 (2048 137)	3162483 (38742 895)	100

Source: Directorate General of Customs of Taiwan

3. Current and potential future supply

3.1 *Aquilaria* spp. and *Gyrinops* spp. in the wild

3.1.1 Ecology

Aquilaria and *Gyrinops* species grow in a range of habitats, including those that are rocky, sandy or calcareous, well-drained slopes and ridges and land near swamps. They typically grow between altitudes of 0-850 m, and up to 1000 m in location with average daily temperatures of 20-22^{o}C (Ding Hou 1960; Afifi 1995; Keller and Sidiyasa 1994; Wiriadinata 1995).

The species of *Aquilaria* are distributed in a wide area covering most of the East Asia Region including India, Burma, Malaysia, Thailand, China the Philippines and Indonesia (Ng et al 1997; Chakrabarty et al 1994; Sidiyasa 1986; Barubah et al 1982 and Whitemore 1972). In Indonesia the six species are distributed almost throughout the country except in Jawa and Lesser Sunda Islands (Wiriadinata 1995; Ding Hou 1960). Distribution of tree species producing gaharu is shown in Table 6.

Table 6. Distribution tree species producing gaharu

No	Species	Geographical distribution
1	*Aquilaria crassna*	Indo-China, Thailand
2	*Aquilaria malaccenssis*	India, Burma, Semenanjung Malaka, Malaysia, Sumatra, Borneo, Philippines
3	*Aquilaria hirta*	Semenanjung Malaka
4	*Aquilaria beccariana*	Semenanjung Malaka,Sumatra,Borneo
5	*Aquilaria filarial*	Philippines, Molusca, Papua
6	*Gyrinops versteeqii*	West Nusa Tenggara (NTB), East Nusa Tenggara (NTT),Papua

Information on taxonomy and morphology of *Aquilaria* spp., is available (CIFOR 1996; Sidiyasa and Suharti 1987; Burkill 1966; Ding Hou 1960). However, information on reproductive biology and factors influencing reproductive success of the species is still lacking. This information is highly important for managing species such as *Aquilaria* spp., which are currently harvested entirely from natural forest. For harvesting of *Aquilaria* spp. to be sustainable, extraction of tree in the wild should not reduce populations beyond the species capability to regenerate. In the absence of knowledge of reproductive success the level of harvest appropriate for sustainable use of the species cannot readily be defined.

Most rain forest trees reproduce mainly or exclusively by seed. When vegetative multiplication occurs, it is normally by means of buds on roots running more or less horizontally near the surface of the ground. Vegetative reproduction is more frequent in tree-like monocotyledons such as *Pandanaceae* (Whitmore 1983). In recent years interest in the species diversity of rain forest trees has focused on breeding systems, information is only available for relatively few species and only tentative conclusion are possible.

Aquilaria malaccensis as tree grows to 40 m in height with a 60 cm diameter trunk. A study from 1996-1998 of the reproductive ecology of six Aquilaria species, including *A. malaccensis*, examined the phenology and seed production and dispersal in Kalimantan, Borneo island in Indonesia (Ding Hou 1960). The study concluded that *A. malaccensis* was a typical under storey tree, that the mature *A. malaccensis* can grow to 40 m in height and that flowering and fruiting occurred in the dry season (when observed in Indonesia's Bogor Botanical Garden).

Pattern of seedling distribution indicate that few seeds are distributed more than a few meters from the adult tree. High germination rates could be reproduced under forest conditions; the potential for seedling recruitment would also be high. However, they noted that the result should be treated with

caution given the relatively small sample and the fact the observations were confined to a single season (Soehartono and Newton 2001).

Studies about leafing, flowering and fruiting periodicity of tropical forest plans both at level of communities and of individual species have been conducted (Bawal et al 1990). This information has revealed considerable spatial and temporal variation in phonological pattern. Species differ with respect to timing, duration and frequency of flowering and fruiting, for example the type of mass flowering that has been observed in the South East Asia rain forest has not been noted in the neotropic. For the above reasons, the understanding of the factors that regulate initiation, periodicity and frequency of flowering mostly remain obscure (Asthon et al 1988).

Information about pollination of trees in tropical forest is still at a very preliminary stage; pollination has been carefully studied only in a very small proportional of rain forest species. Commercial important species, we have limited knowledge about the mode of reproductive biology such as pollination or the extent to which there is a species-specific relationship between pollen vector and plant species, breeding strategy, seed biology, seed dispersal mechanism and genetic structure (Bawal et al 1990; Terborgh 1986 and Chan and Appanah 1980). General, the majority of tropical trees have recalcitrant seed which does not exhibit dormancy, although some exception exist, particularly among shade-intolerant taxa (Richards et al 1996; Whitmore 1990).

3.1.2 Condition in 2006

Indonesia

Ding Hou (1960) in his review of the *Thymeleaeceae* for the Flora Malesiana indicated that six out of the 15 *Aquilaria* and seven out of the eight *Gyrinops* species occur in Indonesia. Four of these *A. malaccensis, A. microcarpa, A. hirta* and *A. beccariana* have a range of local names in Sumatra and Kalimantan, five *A. cumingiana*, *A. filaria, G. versteegii*, *G. moluccana* and *G. decipiens* in Eastern Indonesia, with four further species known from Papua only (*G. ledermannii, G. salicifolia, G. caudata, G. podocarpus*). Five *Aquilaria* species have only been found in the Philippines. Most species are patchily distributed throughout natural forests (Afifi 1995; Levang and de Foresta 1994; Soehartono and Mardiastuti 1997), or scattered on ridges and slopes of well drained land (Keller and Sidiyasa 1994). Agarwood-producing trees have still been reported from several reserves and national parks in Kalimantan: Gunung Palung National Park, Bintuang Karimun Reserve, Mandor Reserve and Gunung Niut. Over-exploitation of Aquilaria species has increased the difficulty finding in Gunung Palung and Gunung Niut (Soehartono and Mardiastuti 1997).

Estimates of the density of mature trees (> 10 cm dbh) of *Aquilaria* spp. in lowland and upland Sumatra and Kalimantan generally show low values: 0.03 and 0.05 ha^{-1} for lowland, and 0.04 and 0.27 ha^{-1} for upland Sumatra and Kalimantan, respectively.. Estimated density of seedling/saplings and trees of *Aquilaria* spp. in West and East Kalimantan, seedlings and samplings was 1.92 and 3.58 individual ha^{-1} , trees >10 cm dbh 0.50 and 0.58 individual ha^{-1} (Soehartono TR 1999). In Northern Bengkulu recorded that the density of individuals of mature *A. malaccensis* was 2.8 ha^{-1} and 0.2 for

offspring, while density for similar species in Southern Bengkulu was 2.8 ha^{-1} for mature trees and 0.6 for offspring.

The decline in lowland forest area between 1990 to 1996 in Sumatra and Kalimantan along with the harvest of gaharu in the two regions (Peters 1996; Sidiyasa and Suharti 1987). Might cause the decline of population of *Aquilaria* spp. in the two areas. The lowland forests in Sumatra which have recently been progressively converted into agricultural land are Riau, Lampung, Jambi, Bengkulu and North Sumatra (Intag 1997). Considerable difficulties have been noted in finding *Aquilaria* spp. trees of 30 cm dbh and greater in regions of Kalimantan (Sidiyasa et al 1986).

Low densities recorded here may therefore indicate that species of Aquilaria are naturally rare, in that they occur at low frequency within the forest communities of which they are a part, as has been suggested previously (Ng et al 1997; Chakrabarty et al 1994; Roesmantyo 1992).

Soehartono and Mardiastuti (1997), a number of secondary threats generally applicable to most forest species are also applicable to *A. malaccensis*, e.g. habitat degradation and lost resulting from forest fires, forest conversion to plantation (including forest plantations), logging and land mining concessions and the creation of settlement areas for transmigration peoples. Locations of agarwood, showing the province, regency and location where harvests are undertaken as shown in Annex 1.

Malaysia

Malaysia has a long history in the trade in agarwood. Agarwood has long been collected by the indigenous peoples of the interior of Peninsular Malaysia to supplement their income. Other local people are also involved involved in collecting, particularly in the State of Kelantan. Agarwood is referred to gaharu or garuwood in Malaysia, the Sanskrit wood garu meaning heavy. It has been reported that Malaysian agarwood can also be sourced from some *Gyrinops* spp., which are more prevalent in peat-swamp forest. The aromatic wood from *Gyrinops* spp. together with with other fragrant woods is also trade under the name gaharu, which further complicated efforts to study trade volumes and trends in *Aquilaria* spp.

Within Peninsular Malaysia, the National Forestry Act, 1984 prohibits the felling of *A. malaccensis* from state forest or permanent Forest Estates. Harvesting from national park or wildlife sanctuaries is prohibit by the Protection of Wildlife Act, 1972. Under the National Forestry Act, illegal removal of forest products is subject to fines of up to MYR2000 (USD 526) and/or imprisonment up to 12 months. A removal of Minor Forest Product permit is required to harvest all *Aquilaria* spp. from Peninsular Malaysia. Permits cost MYR100 (USD 26) and are renewable annually.

In Serawak *A. malaccensis* harvesting from national parks or wildlife sanctuaries is prohibited by the national Park and Reserves Ordnance, 1988 and the Wildlife Protection Ordnance, 1988. Illegal removal of Sarawak's protected plants can result in imprisonment of up to 12 months or fines of MYR10000 (USD2631) (A.B Othman, Director Crop Protection and Plant Quarantine Services Division, Department of Agriculture, Malaysia, in litt to CITES Secretariat, 22 January 200).

In Sabah *Aquilaria malaccensis* harvesting from State land (government forests and gazetted park and their equivalents) is forbidden by the Parks Enactment Act 1984. Illegal exporters are subject to fines

not exceeding MYR500 000 (USD131 555) or imprisonment under the forest Enactment and C.F. Circular 1/83. For more general offences such as the altering and counterfeiting of documents and permits relating to the provisions of the Forest Enactment, the fine is MYR 5000 (USD 1316).

Additionally, collectors are charged a premium fee that varies with each State. In Perak (Peninsular Malaysia) the collector's fee is MYR 100/200/ha (USD 26/200/ha) and an additional royalty fee of MYR 18/t (USD 5/t) applies to all *Aquilaria* spp. (Traffic Southeast Asia 1999).

Population density of *A. malaccensis* recorded at Pasoh Forest Reserve, Malaysia of ≥ 1 cm was 2.5 ha^{-1} and density for langer trees (> 10 cm dbh) was less then 1 ha^{-1} (La Frankie 1994).

India

Aquilaria khasiana and *Aquilaria malaccensis* is both to be found in India, mainly in the Khsi Hills of Meghalaya (Kanjilal et al 1982). *Aquilaria malaccensis* is native to nine north-eastern States: Arunachal Pradest, Assam, West Bengal, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. The species is typically found growing at altitudes of up to 1000 m, being localized mainly in the foothills and undulating slopes of evergreen and semi-evergreen forests (Chakrabarty et al 1994). The status of wild *A. malaccensis* has steadily deteriorated with few natural agarwood stocks remaining. According to information gathered by Forest Department and the Regional Deputy Director of Wildlife Preservation, Eastern region wild *A. malaccensis* is "rare" in all of the above-mentioned States (apart from Sikkim and West Bengal where its status was not commented upon).

Surveys undertaken by the regional CITES Management Authority in Tripura indicate that the natural stock is almost exhausted in that State as well. In Mizoram *A. malaccensis* grows sporadically in some of the catchment area of main river tributaries such as Tuivawl.

3.1.3 Cost of collecting Gaharu

The collecting gaharu are classified here into short and long visit. The short visit varied from one to seven days while the long visit lasted 14 days untilas long as 90 days. Many collectors (73 %) search for gaharu are becoming harder and harder, the length of visit to the forest have increased in day and because short visit often get zero result, they prefer to go for long visit. Each middlemen is likely to employ between two to seven people for short visit and seven to 60 people for long visit depending on the region and amount of money they have available for the visit.

For a short collection visit the collector normally borrows $US 15-75 from the middlemen or local traders. However for a long visit they could borrow from the traders as much as $US 1,000- 2,000. These amounts of money are not fully used during the visit. Half or more of the money was split up among the group and left behind for their own families. Cost of trips for gaharu collector in Riau, West Kalimantan and East Kalimantan (Table 7.) (Soehartono 1999).

Table 7. Cost (in US $) of short trip (S) and long visits (L) for gaharu collector in 1996 to 1998

Basic items	Cost of collectors for searches Gaharu in different regions ($ USD)					
	Riau		West Kalimantan		East Kalimantan	
	S	L	S	L	S	L
Petrol	0.00	5.00	0.00	0.00	0.00	0.00
Cooking Oil	0.85	12.00	0.00	2.00	0.00	2.50
Salt	0.50	2.95	0.30	3.50	1.50	11.25
Coffee	0.35	12.50	0.65	15.00	1.50	20.75
Sugar	0.40	7.30	0.60	15.00	3.15	20.50
Cigarettes	1.65	30.00	3.15	35.00	**7.50**	**57.00**
Noodles	0.80	20.00	2.50	10.00	2.50	5.43
Salted-Fish	0.50	11.00	0.45	3.70	0.50	1.00
Medicine	1.00	7.50	0.50	2.50	1.00	43.50
Batteries	7.50	22.50	5.00	25.50	5.00	26.15
Matches	0.30	3.60	0.30	3.00	0.90	3.50
Rice	2.25	**30.50**	**10.05**	32.50	2.50	18.20
Transport fees	**8.00**	27.00	8.00	**42.50**	0.00	0.00
Utensils	7.50	12.50	2.50	15.00	1.70	17.50
Plastics	5.00	20.00	8.00	12.00	7.50	17.50
Total	**36.60**	**224.35**	**42.00**	**217.20**	**35.25**	**244.78**

Sources: Soehartono 1999. Note: Short visit: 2 weeks, Long visit: 1-1.5 months

Net margin analysis on market institutions of gaharu collectors and middlemen point to the importance of "patron-client" relationship in the distribution of net benefits. Collectors without "patron-client" relationship can benefit from better prices. Details of the net margins in Gaharu trade in East Kalimantan are shown in Table 8 (Kurniawan 2003).

Table 8. Net Margin Gaharu Trade in East Kalimantan, 2000

Market Level	**Item**	**Average cost and Net Margin on Market system**	
		Patron-Client	Free
Gaharu Collector			
1. Capital	Rp/month	184 375	0
2. Cost of labour	Rp/ month /man	315 000	0
3. Income	Rp/ month	284 524	0
4. Net Margin	Rp/ month	- 214 851	0
Middlemen			
1. Capital	Rp/ month	3 022 727	4 875 000
2. Transportation cost	Rp/ month	377 273	736 667
3. Income	Rp/ month	3 274 175	7 365 625
4. Net Margin	Rp/ month	- 125 825	1 753 958
District Trader			
1. Capital	Rp/ month	0	19 925 000
2. Transportation cost	Rp/ month /man	0	375 000
3. Income	Rp/ month	0	36 875 000
4. Net Margin	Rp/ month	0	16 575 000

Source: Kurniawan 2003

3.2 *Aquilaria* spp. domestication

3.2.1 Condition in 2006

Indonesia

Based on the information from ASGARIN (*Asosiasi Pengusaha Eksportir Gaharu Indonesia*/ Association of Indonesian Gaharu [Agarwood] Exporters), several companies along with the local community have begun artificial propagation of *Aquilaria malaccensis*, *A. beccariana*, *A. microcarpa and Gyrinops versteeghii*. Table 9 below shows the companies and the total area of trees they have planted. In some companies, the age of the plantation is more than 10 years, but in terms of the agarwood produced, the plantation is only shown a good progress. This means that currently no production is coming from plantations, even though some plantations, such as those undertaken by PT Budi Daya Perkasa in Pekanbaru, Riau have known to produce good quality gaharu woods. However, research and studies on the agarwood production is continued.

Table 9. Gaharu plantation undertaken by some companies and local communities

No	Company/local community	Location	Area of plantation
1	PT. Budi Daya Perkasa	Sumatra	15 ha
2	CV. Megah Aroma Utomo	Sumatra	3 ha
3	CV. Subur Raya	Sumatra	3,5 ha
4	Jambi local community	Sumatra	30 ha
5	Lampung local community	Sumatra	10 ha
6	Metro local community	Sumatra	1000 trees
7	Mentawai community	Sumatra	2 ha
8	PT. Sumber Alam Jaya	Borneo	3 ha
9	CV. Kuda Mas	Borneo	2 ha
10	Dayak community – Central Kalimantan	Borneo	2 ha
11	CV Emas hijau	Lombok/NTB	6 ha
12	Nusa Cendana University	Lombok/NTB	200 ha

Inoculation with *Fusarium* fungi on domesticated *Gyrinops* spp. has been tried on 6 years old trees or tree with diameter > 20 cm or tree in flowering stage. The result of this experiment indicated that the quality of agarwood affected by the period of inoculant infected the tree (Table 10 and Figure 3).

Tabel 10. Percentage and quality Gaharu/agarwood production after inoculation

Year after inoculation	Quality	Percentage production
0.5	Kemedangan:	
	Class III	100%
1	Kemedangan:	
	Class I	30%
	Class II	60%
	Class III	10%
2	Kemedangan:	
	Class I	80%
	Class II	15%
	Class III	5%

Source: Mulyaningsih, June 2006 (Personal communication)
Laboratory of Biotechnology, Mataram University

Figure 3. Agarwood (Aloeswood) from various parts of Indonesia one or two years after inoculation in experiments at FORDA (Sumarna 2005, 2016)

Malaysia

The first cultivate of Aquilaria occurred in 1928 (Lok and Zuhaidi 1996). Natural mortality caused the original population density of this stock of 833 ha^{-1} to decrease to 31 ha^{-1} by 1995 and it is unknown whether any of these trees produce gaharu/agarwood. Additional research has shown that Aquilaria can be artificially propagated and there are continuing laboratory experiments regarding artificial induction of agarwood formation.

Thailand

Aquilaria crassna and *Aquilaria malaccensis* are native to Thailand (Oldfield et al 1998) and *Aquilaria baillonii* may also occur here (Heuveling van Beek and Phillips 1999). No information was available regarding the population status or distribution of *Aquilaria* spp. in Thailand.

Some small-scale *Aquilaria malaccensis* research plots in Thailand. Shyun (2000), of the Medicinal Plants Division reports that a study on *Aquilaria crassna* was undertaken during the late 1980s at the the Kesatsart University (Traffic International, 8 May 2000). The first plantation *Aquilaria crassna*, known as the Gridsanah Botanical Gardens of Aloeswood, was establish in 1994. The status of this and other plantations in unclear (Heuveling van Beek and Phillips 1999).

Vietnam

In Ha Tinh, Kon Tum and Phu Quoc Island government plantations of Aquilaria is exist. One trader reported a joint venture with a Japanese enterprise to grow Aquilaria in Dat Lat. The Rain Forest Project (TRP) has successfully implemented a pilot project “Sustainable Agarwood Production in Vietnamese Rainforest” which is being undertaken in two southern locations (Ba Nut and Phu Quoc), and which is now expanding to the central highlands of Kon Tum Province. The result indicate that agarwood plantation have *the potential to be developed into agroforestry* enterprises providing long-term and stable sources of agarwood, which could provide an opportunity to generate revenue for low-income families. Persoon and van Beek (2008) discussed progress in Vietnam in developing gaharu as smallholder agroforestry commodity.

India

The lack of plantation in Mizoram and Meghalaya has resulted in much ilegal harvesting from natural forest. *A. malaccensis* in Nagaland and Manipur is so depleted that a large proportion of the raw agarwood used by processing units in these two States is sourced from neighbouring countries.

The silviculture Division of Arunachal Pradesh has converted large areas of degraded forests into commercial agarwood plantations. These are the source of most of Arunnadhal Pradesh's illegal stock, despite their being too immature to yield commercially valuable agarwood. The upper Assam climate provides particularly suitable growing conditions and large –scale plantation exist in this State. Owners of private plantations in Assam have also attempted artificial fungal inoculation of two- to three-year-old *Aquilaria malaccensis* plants, but it is not know how effective this has been at stimulating agarwood production.

Surveys undertaken by the CITES Management Authority in Tripura estimate that approximately 450-500 ha of private agarwood plantations exist in the north district. Government plantations also exist in Tripura, where the Forest Department first created plantations in the 1960s. There has been little effort to create agarwood plantations in either Mizoram or Meghalaya. Some Government plantations can be found in Nagaland and Manipur, but there are few private plantations in these States.

3.2.2 Cost of Gaharu domestication

Through gaharu domestication, farmers will get a good benefit. Sumarna (2005), reported that he expected a benefit of around US$ 266.000 based on the assumption that in a 10 years production period, with 60% of 1000 seedlings per ha can be harvested and that a farmer planting in his own land is not subject to NTFP levies.

Detail of cost benefit analysis and some parameter related to feasibility gaharu domestication shown in Table 11.

Table 11. Benefit cost and feasibility analysis of domestication gaharu

Items of activities	Volume	Unit	Prices (US $)	Amount (US $)
A. Production Cost				
1. Seedling	1000	trees	1,67	1670
2. Plantation	50	working day	1,11	55,5
3. Fertilizer	1000	kg	0,23	230
4. Compost	2000	kg	0,06	120
5. Labor	96	month	55,56	5333,76
6. Inoculant and stressing agent	1	unit	2055.56	2055.56
7. Inoculation cost	300	working day	6,67	2001
9. Harvest	1000	trees	5,56	5560
Total				17025,82
B. Production (60%)				
1. Grade gubal	600	kg	222,22	133332
2. Grade kemedangan	6000	kg	16,67	100020
3. Grade abu/bubuk	9000	kg	5,56	50040
Total				283392
C. Profit (B-A)				266366,18

D. Feasibility gaharu domestication		
1. Break event point of production		
Cost production gubal	73.75	kg
Cost production kemedangan	983.33	kg
Cost production ash	2950	kg
2. Breakeven point of price (BEP)		
Cost production gubal	2731,48	US$
Cost production kemedangan	273,148	US$
Cost production ash	182,099	US$
3. Benefit cost ratio (B/C)	17.29	
4. Return of investment (ROI)	1628.81	%

Source: Yana Sumarna 2005

4. *Ex ante* impact appraisal of new gaharu technology

Under the assumption that biotechnology will be (or become) effective in transforming *Aquilaria* trees into agarwood (Gaharu), the yield of gaharu oil per working day can be predicted in different production systems. In natural forest, trees are hard to find, but no labour beyond the harvesting expeditions is needed. Mixed in with rubber in rubber agroforest, or as dedicated plantation, labour is needed to establish the trees and subsequently inoculate them. Table 12 specifies the main assumptions and parameter values used for such a comparison.

Table 12. The parameters used in the model prediction

Trees		
	Allometric woody biomass/DBH: intercept	0.05
	Allometric woody biomass/DBH: power	2.6
Product chain		
	Oil extraction efficiency, g/g	0.7
	Scaling rule for harvest time/biomass	0.8
	Middlemen margin	0.4
Prices		
Qual I	USD / kg chips	1500
Qual II	USD / kg chips	200
Qual. III	USD / kg chips	20
Qual I	g extractable oil / kg chips	150
Qual II	g extractable oil / kg chips	25
Qual. III	g extractable oil / kg chips	3
Qual I	USD/ g extractable oil	10
Qual II	USD / g extractable oil	8.0
Qual. III	USD / g extractable oil	6.67

Production systems Assumptions	Natural forest	Rubber agroforest + Aquilaria	Aquilaria plantation
Fraction of trees infected	0.1	0.4	0.4
Harvestable agarwood content fraction kg/kg	0.1	0.1	0.1
Sustainable harvest cycle (years)	50	35	12
Area in Indonesia, M ha	30	3	0.004
Search & travel time, days/ha	6	0.5	0.5
Management time, days/ harvestable tree (10 cm dbh)	0	8	12
Harvest time days/tree (for tree of 10 cm dbh)	1.5	1	1
Fraction in Quality I	0.1	0	0
Fraction in Quality II	0.4	0.2	0.2
Fraction in Quality III	0.5	0.8	0.8
Number of trees/ha, 10 cm DBH	0.447	60	240
Number of trees/ha, 20 cm DBH	0.05	20	150
Number of trees/ha, 30 cm DBH	0.0029	0	10
Number of trees/ha, 40 cm DBH	0.001	0	0
Result indicators			
Harvestable & extractable oil, g/ha	3.7	747.6	5458.3
days of work per ha per cycle	6.8	785.1	5773.0
g oil day of work	0.542	0.952	0.945
USD per day of work at current prices	2.5	4.0	3.9
kg oil per habitat in Indonesia	2,205	64,078	1,819

A key result of the calculations is that the gaharu oil yield per day of work can be expected to double in the domesticated production modes: from 0.542 g in natural forest, to 0.952 g in agroforest + *Aquilaria* and 0.945 g in a dedicated *Aquilaria* plantation. This result, however, assumes a continuous production system, where labour spent on planting and caring for young trees can be offset by concurrent harvests. The associated income per working day can be calculated as USD 2.1 in natural forest, USD 4.0 in agroforest + Aquilaria and USD 3.9 in a dedicated Aquilaria plantation.

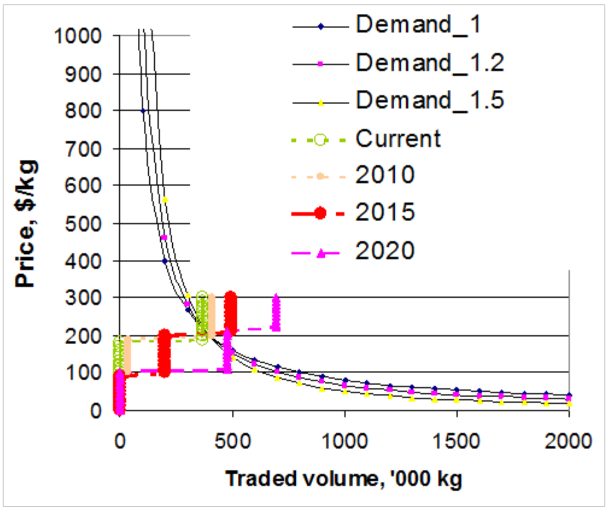

Figure 4. Predicted supply and demand relationships for Gaharu in Indonesia under the assumption of a rapid adoption by rubber agroforest farmers of Gaharu as an additional component of their production system

If compared with natural forest, with labour paid at the same wage rate and equivalent agarwood quality II (chips), rubber agroforest and *Aquilaria* plantations are expected to "undercut" collection from the wild between 2010 and 2015. Predicted domesticated production and impacts on the price level are shown in Figure 4.

Between 2010 and 2020 domesticated sources are expected to fully replace forest collection, with a fall in price by a factor of about 2. Early adopters among the rubber (ant other) agroforest owners in the relevant agro-ecological domain are likely to benefit substantially, while later adopters will still get a resource competitive to rubber trees per unit space. Active spreading of knowledge on the agarwood biotechnology is in the interest of the managers of diverse rubber agroforests.

5. Discussion

With the benefit of hindsight, the predictions of section 4 made in 2006 of a 50% drop in market prices has not yet materialized. Market demand has continued to grow, unhindered by CITES regulations. Exports to China have increased considerably[2]. A recent trade deal between Saudi investors and Indonesia[3] specifies *gaharu* wood imports worth of Rp100 billion (USD 7.5 million), without specifying the source as either natural forest or domesticated plantations. Market prices are quoted as 200-350 USD/kg for premium quality, and 1000 – 10,000 USD/kg for gaharu oil[4]. The Wikipedia entry[5] still refers to natural resources, and describes the domesticated from as 'fake'. Planting material, however, is readily commercially available, with prices of 1-3000 Rp per seedling depending on size[6]. Demonstration projects on gaharu planting are reporting successes[7]. The replacement of natural by cultivated gaharu is probably a matter of time, and the window of opportunity for early adopters of gaharu may close soon.

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[2] http://www.gaharuonline.com/news/gaharu_indonesia_potential_increase.htm

[3] https://en.tempo.co/read/news/2016/07/14/056787687/Saudi-to-Import-Gaharu-Wood-from-Indonesia

[4] https://www.alibaba.com/showroom/indonesia-gaharu.html

[5] https://en.wikipedia.org/wiki/Agarwood

[6] https://bibitgaharuku.wordpress.com/tag/pt-borneo-nusantara-international/

[7] http://www.itto.int/files/itto_project_db_input/2866/Technical/TECHNICAL%20REPORT%20NO.%204%20%20Establishing%20of%20Demonstration%20Plot%20of%20Eaglewood%20Plantation.pdf

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Videos of Agarwood collection in the wild:
https://www.youtube.com/watch?v=hCQ2OYtg9ZM

Agarwood utilization:
https://www.youtube.com/watch?v=CWJAXRJdqhA
https://www.youtube.com/watch?v=jv69pYSm2oo

Inoculation technique:
https://www.youtube.com/watch?v=5fUWnFlFDGM

The secret of agarwood:
https://www.youtube.com/watch?v=v1NwvCGQm9U

Annex

Annex 1. Locations of Agarwood, showing the province, regency and location where harvests are undertaken

No	Province	Regency (Kabupaten)	Location (Sub-regency/ Kecamatan)
1	Aceh	Tapak Tuan, Meulaboh	
2	North Sumatra	Natal, Salapin	
3	Riau	Merlung, Ketapang	
4	West Sumatra	Painan, Kota Nopan Mentawai islands	
5	Bengkulu	Kaur, Manna, Seluma Bengkulu Utara, Rejang lebong Kotamadya Bengkulu	Bintuhan, Nasal, Kaur Utara, Maje, Segini, Kedurang, Talbo Tais, Sukaraja, Muku-muko, Ipu, Ketahum, Arga Makmur, Muara Aman, Kepoliang, Talang empat air, Sebakul
6	Jambi	Batanghari, Muara Tembesi Surolangun, Bangko, Merangin	
7	South Sumatra	Lubuk Linggau, Lahat Baturaja	
8	Lampung	Liwa, Krui Lampung Tengah	Way Kambas
9	West Kalimantan		Sambas, Singkawang Serimbau, Noyan Selakan, Sebatu Putusibau, Kawit
10	Central Kalimantan		Luwu Huyu, Tamalung Lewankaji, Kuala Kurun Tumbangolon, Kuala Kapuas
11	South Kalimantan		Astambul, Rantau, Barabai, Bayu Tawar, Putik Layung, Tanjung Hulu, Lasung
12	East Kalimantan		Damum Parai, Buma (Mal), Long Pujungan (Mal), Malinau (Mal), Long Pesi, Muara Calong
13	North Sulawesi/ Gorontalo	Kota Mobago, Toli-toli Palele, Limbato	
14	Central Sulawesi	Donggala, Poso	Paguyaman, Santigi, Gunung Tinombala, Malino Watuawu, Balingara, Batui
15	South Sulawesi	Mamuju Palopo Utara	Malili Pasang Kayu
16	South East Sulawesi		Tangkele Boke, Meluhu, Mengkoka
17	North Maluku (Moluccas)	Halmahera	Tobelo, Galela Taliabu, Obi
18	Maluku (Moluccas)	Seram	Buru, Wetar
19	West Nusa Tenggara	Lombok island Sumba island	Gunung Rinjani, Mulur, Tekara Batu Lanteh, Sernamung, Bersanak, Ampang, Malawa, Cenggu, Dompu, Rakore
20	East Nusa Tenggara	Sumbawa island Flores island West Timor	Waikabubak, Ngadubelu, Ngalu Boleng, Bajawa, Detusoko, Alor Manungan, Resikama, Soe
21	Papua (Irian Jaya)	Jayapura Jayawijaya Manokwari Merauke Nabire Sorong Yapenwaropen Mimika Puncak Jaya	Ganyem, Dabra, Lerek Tiom, Yamin, Oksbil Arfak, Oransbari, Bintuni Keira, Bade, Tanah Merah, Sawaerma S. Tabah, Wandai, Barapasa, Kumupa Ayamaru, Peg. Arfak, Tamrau P. Korido, namber, Korin Otakwa, Tembagapura Gumbuyuh, Puncak Jaya, Mulia

Source: ASGARIN 2004

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