CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

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EXPENSIVE, EXPLOITED AND ENDANGERED
A REVIEW OF THE AGARWOOD-PRODUCING GENERA *AQUILARIA* AND *GYRINOPS*: CITES CONSIDERATIONS, TRADE PATTERNS, CONSERVATION, AND MANAGEMENT

1. This information document is submitted by the Secretariat on behalf of the International Tropical Timber Organization (ITTO) in relation to agenda item 62 on *Agarwood-producing taxa (*Aquilaria *spp. and* Gyrinops *spp.)* and specifically in relation to document CoP19 Doc. 62.1

2. The text of the report "*Expensive, exploited and endangered – a review of the Agarwood-producing genera* Aquilaria *and* Gyrinops*: CITES considerations, trade patterns, conservation, and management*" commissioned by the Secretariat in the framework of the CITES Tree Species Project (CTSP) is included in the present information document.

3. The report is based on a study that was validated by the Agarwood range States during a workshop hosted by Malaysia and ITTO (20-23 June 2022, Kuala Lumpur) with the support of the CTSP. At the time of writing, the final report is being prepared for publication in all three CITES languages.

Expensive, Exploited and Endangered

A review of the agarwood-producing genera *Aquilaria* and *Gyrinops*: CITES considerations, trade patterns, conservation, and management

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CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) is an international agreement between governments. Its aim is to ensure that international trade in specimens of wild animals and plants does not threaten the survival of the species in the wild.

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Front-cover photo: Adult tree of *Aquilaria malaccensis*, Penang, Malaysia. Photo: Lau Kah Hoo

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Abbreviations and acronyms

CITES	Convention on Trade in Threatened and Endangered Species of Wild Fauna and Flora
cm	centimetre(s)
COP	Conference of the Parties
DART-TOFMS	Direct analysis in real time (time of flight) mass spectrometry
dbh	diameter at breast height
ha	hectare(s)
ITTO	International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
l	litre(s)
m	metre(s)
NDF	Non-detriment finding
PEC	2-(2-phenylethyl) chromone
PC	Plants Committee
POC	Province of China
USD	United States dollar(s)
SAR	Special Administrative Region

Executive summary and recommendations

Agarwood is a highly valued non-timber forest product produced primarily in Southeast and South Asia from two main tree genera: *Aquilaria* and *Gyrinops*. The wood is used for cultural, cosmetic, and medicinal purposes, although most is burned as incense. All members of both genera (at least 28 species) are listed in Appendix II of the Convention on Trade in Threatened and Endangered Species of Wild Fauna and Flora (CITES), and several of the predominant species are classed in the Red List of the International Union for Conservation of Nature (IUCN) as either critically endangered or endangered, while several others are recorded as "data deficient". Not all species produce agarwood, however, and the taxonomy of these two genera is not settled, requiring reassessment to reduce confusion. The declining status of these trees has resulted from high demand for agarwood that has led to decades of unsustainable harvesting. The percentage of trees with agarwood in the wild is likely less than 10%, but unfortunately the trees are most often cut down to determine whether agarwood is present.

The most abundant species, *A. malaccensis*, was listed by CITES in 1995, with all other species added to Appendix II in 2005. CITES deliberations about the species have continued, with discussions about terminologies for products, developing proper non-detriment finding (NDF) reports, whether some products should be exempted from regulation, and how the products are recorded by exporters. The most contentious issue among exporting countries is the blanket listing that includes plantation-origin products, which are not endangered, along with the wild stock, which is declining. A major challenge remains the difficulty in distinguishing between wild and plantation agarwood in trade. Recent research seems to have solved this dilemma using DNA barcoding and/or gas chromatography/mass spectrometry. However, the problem for developing countries is access to the proper equipment, the cost of testing, and the need for trained personnel to carry it out.

The only global data on the export and import of agarwood are from the CITES database, which records information from export permits submitted by exporting countries. These data indicate that most Southeast and South Asian countries export raw agarwood, or agarwood products, such as oil, carvings, and incense. Still, most agarwood is exported as chips to Middle Eastern countries, Singapore and Taiwan Province of China (POC) for further processing. There are estimates that the global industry is worth more than USD 30 billion, with a litre of oil commanding a price of USD 40 000–50 000. The major exporters of *Aquilaria* are Indonesia, Malaysia, and Thailand, with almost exclusively (more than 98%) wild stock exported from Malaysia and Indonesia, while the wood from Thailand is all plantation-origin. The main countries that import *Aquilaria* include the United Arab Emirates, Saudi Arabia, Singapore, and Taiwan POC. About five times more *Aquilaria* is exported on an annual basis than *Gyrinops*. The major *Gyrinops* exporters are Indonesia (including Papua) and Sri Lanka. Starting in 2017, more plantation-origin than wild-origin agarwood exports were recorded in the CITES database. However, plantation agarwood is apparently of inferior quality and is worth less than wild agarwood, so demand for wild stock remains very high.

The chronic unsustainable harvesting of wild agarwood seems to have been ignored by governments in favour of supporting their export industries. As wild populations have become increasingly depleted, and as a result of the CITES listing, industry and governments have responded by developing plantations, especially of *A. malaccensis*, *A. crassna*, and *A. sinensis*. Plantations are now found throughout South, East and Southeast Asia, with very large plantations in India, Thailand, Viet Nam, Malaysia, Indonesia, and China. The total number of plantation trees may have exceeded 60 million in 2022.

The science of producing plantation agarwood has advanced considerably since the initial listing of *Aquilaria* by CITES. Research has focused on the fungi that cause agarwood to form as part of a tree's natural defense mechanisms. In wild trees, wounds and infection result from ants and wood-boring insects that import fungi and other pathogens into the trees. The trees react by producing resin that contains a large array of aromatic chemicals and hardens to form agarwood. Plantation operators duplicate the process by drilling holes in the trees and introducing fungal inoculants identified as those which cause agarwood to form. As a result of research and trial-and-error, a series of best practices have been developed to improve the production of agarwood. Trees take about eight years to reach 10 cm diameter at breast height (dbh), the recommended size for inoculation, followed by two years or more for the agarwood to develop.

Despite the development of plantations, the harvesting of wild agarwood is still permitted, though under some restrictions in Malaysia and Indonesia. Illegal harvesting also continues. Numerous instances are found each year, and some illegally harvested wood is mixed with plantation wood of the same quality to circumvent harvest laws. While national policies continue to be primarily directed towards the export industry, there are now some conservation measures in place in all countries, including wild tree restoration programmes, laws and quotas restricting or banning wild stock harvest, and registration systems for the buying, transport, and export of agarwood, including that from plantations.

A major impediment to the sustainable management of agarwood is the lack of information about the status of wild populations. There are few survey data to underpin the NDFs on which sustainable annual allowable harvests can be based. Just four countries have produced an NDF, with those from Malaysia and Indonesia now well out of date. While the NDFs from India (2021) and Thailand (2016) were not available for this study, information presented at a CITES agarwood workshop in 2022[1] indicated that both are robust. Quotas have been set by some countries for the harvest and export of wild agarwood, but in the absence of population data, such quotas have no scientific basis.

Recommendations from the review are listed below.

For range states:

- Develop and implement periodic sampling to establish population data for all agarwood species (in plantations and the wild), and develop proper NDFs with quotas for all individual agarwood species.
- Ensure protection of wild trees through improved regulation and enforcement, and also possibly through the expansion of protected areas.
- Establish and strengthen national/regional databases for the identification of the origin of agarwood specimens. The database could contain site-specific profiles (including DNA profiles) of agarwood-producing species from range states.
- Increase the capacity and knowledge of enforcement staff and customs officers to more effectively reduce illegal harvesting and exporting.
- Establish a national registration system for plantation and wild agarwood:
  - Develop a licensing system for traders (such as India's "legal procurement certificate"), with any illegal activities by a trader resulting in the loss of the trading license.
  - Develop and implement online technologies to support the registration and monitoring process for plantations, nurseries, and for exporters.

[1] https://www.itto.int/direct/topics/topics_pdf_download/topics_id=7115&no=1&file_ext=.pdf?v=

    - Control the acquisition of parent stock from private or state lands, or purchased internationally.
    - Verify all plantations through inspection.
    - Apply transportation permits.
    - Samples of the labels used and lists of exporters should be communicated to the CITES Secretariat by exporting states, and then provided to all Parties through a Notification.
- Develop and implement conservation action plans for the agarwood species, including a component for assisted natural regeneration.
- Consider creating a national agarwood species fund that would collect fees paid by users of agarwood-producing populations. The funds should be used to strengthen the implementation of national strategies to ensure the conservation and sustainable management of agarwood species.
- Out-planting programmes for agarwood species should consider genetic diversity within species and should not move seeds, seedlings, or cuttings outside the distribution range.
- Range states might wish to consider negotiating and agreeing to implement a common grading system for agarwood products based on the aromatic compounds present, colour, or other scientifically measurable characteristics.
- Range states should consider applying to funding agencies such as the Asian Forest Cooperation Organization, ITTO, the United Nations Development Programme, and others for support to develop their agarwood management plans.
- Technologies to distinguish wild from planted agarwood exist; plans could be developed/negotiated to establish regional service laboratories to carry out such analyses.

For Importing countries:

- Given the lack of funding for the conservation of agarwood species, from the major importing countries might reflect on the damage already done to wild populations and consider assisting range states to restore and recover wild populations, either directly or through international agencies working towards the conservation and sustainable management of forests.
- Importing countries need to adopt technologies to distinguish between wild and plantation agarwood and apply these technologies to samples of incoming agarwood on a regular basis. Further, importing countries need to upgrade the skills and knowledge within their customs agencies to ensure the legal importation of agarwood.

For CITES:

- CITES should consider obtaining funding to work with a botanical garden (e.g. Royal Botanical Gardens, Kew) to develop a clear taxonomy for the two genera *Aquilaria* and *Gyrinops*, then consider listing the species individually, in part based on whether they are agarwood species.
- It is clear that most countries have spent considerable time on developing plantation methods, but limited time on understanding the importance of an NDF; as a result, CITES should consider working further with range states to provide improved information and training on developing an NDF.
- Parties to CITES should consider whether additional agarwood-producing species (such as *Aetoxylon sympetalum,* an important source of agarwood in Sarawak) should be included in Appendix II to make international trade regulations more comprehensive.
- Parties to CITES should consider whether existing regulations and export quotas adequately safeguard rare and endemic agarwood species such as *Aquilaria rostrata*.

- The current CITES ”glossary of agarwood products” requires further work to reduce its scope and ensure that there is clarity of the terms.
    - All products should be reported in kilograms, except live specimens reported in numbers.
    - ”Wood block” and ”piece” should be a single category.
- The Plants Committee should discuss further with all range states whether the exemption of exhausted agarwood powder from CITES controls should be maintained.
- Inconsistencies in the agarwood import/export database should be addressed by working with countries to develop consistent terms for products (in line with the glossary) and to specify that products must be reported in certain units of measurement. Further consideration might be given to developing an online portal for direct information input that will only accept certain terms and units.
- Consider providing guidance on: a) the appropriateness of establishing quotas based on weight or volume; b) the extent to which such quotas relate to the number of mature standing trees, using a precautionary approach; and c) focusing on the harvesting regime rather than using standard conversion factors.

1 Introduction

Agarwood is a non-timber forest product valued for its aromatic, medicinal, and cultural uses. Agarwood is also known variously as eaglewood, aloeswood, gaharu (Malay), chen xiang (Chinese), jin-koh (Japanese), oudh or oud (Arabic), mai kritsana (Thai), and tram huong (Vietnamese), among many other vernacular and trade names (Barden et al. 2000). Primarily sourced from two tree genera, *Aquilaria* and *Gyrinops*, the aromatic and medicinal properties of agarwood derive from resinous deposits in the tree's heartwood. The genera *Gonystylus* and *Aetoxylon* also produce some agarwood, but not at a commercial scale. Agarwood is a highly valuable commodity (see Section 4) that has often been described as the most expensive wood in the world.

Figure 1: Inflorescence of *A. malaccensis*, Penang, Malaysia. Photo: Lau Kah Hoo

Sources of agarwood

Agarwood plants are classified in the family *Thymelaeaceae*. The taxonomy of this diverse family is not settled, with the consequence that there are between 19 and 31 species in the genus *Aquilaria,* depending on the taxonomist compiling the list. Among them are at least 13 species that produce agarwood (Kaura and Kaushik 2017). Agarwood is also produced by the genus *Gyrinops*, of which there are at least 8 species (some taxonomists place additional species here rather than in *Aquilaria*). Table 1 lists 28 of the species from the two genera.

Distribution and status

Among the *Aquilaria* species, IUCN lists four as critically endangered, one as endangered, eight as vulnerable, and the rest as "data deficient". *A. malaccensis* (Figure 1) has been the most important of the agarwood species (Hou 2006), occurring in India, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Bangladesh, Bhutan, and Thailand (Oldfield et al. 1998; Chua 2008), where it is now listed as critically endangered by the IUCN. Range states for the other *Aquilaria* spp. also include Brunei Darussalam, Cambodia, China, the Lao People's Democratic Republic, Papua New Guinea, and Viet Nam (Table 1). More recently, *A. crassna* has become a second species common in trade because it is increasingly grown in plantations, and now supplies almost as much agarwood globally as *A. malaccensis*. Other exported agarwood comes from *A. acuminata (or A. filaria), A. beccariana, A. microcarpa, A. sinensis*, and *A. subintegra*. The ranges of these species are not entirely contiguous, and most are restricted in distribution to just a few countries (Table 1).

Regarding *Gyrinops,* most agarwood is derived from: *G. versteegii, G. caudata, G. ledermanii*, and *G. walla*. Among the *Gyrinops* species, four are endangered or critically endangered, while all others are listed as vulnerable by IUCN. *Gyrinops* spp. are distributed in much of Southeast Asia, including Sri Lanka, Indonesia, Thailand, and Papua New Guinea (Table 1).

Lee and Mohamed (2016) and Turjaman (2022) have argued the need for better taxonomy for the *Aquilaria* spp. to ensure preservation of the full genetic diversity of the genus. For example, a new species, *A. rugosa* was described by Kiet and Kessler in 2005 (Gratzfeld and Tan 2008). All range states (except Singapore, which does not harvest its native species) have in common declining wild tree populations due to chronic overharvesting and increasing forest habitat conversion to other land uses (TRAFFIC 2004; UNODC 2017).

Table 1: *Aquilaria* and *Gyrinops* spp. IUCN Red List status, and range states (Wang et al. 2021; Turjaman 2022; and POWO 2019).

Species	**IUCN status***	**Range states**
Aquilaria malaccensis Lam.	CR	India, Myanmar, Bhutan, Malaysia, Indonesia, Philippines, Thailand, Singapore, Bangladesh, Nepal
Aquilaria microcarpa Baill	EN	Brunei Darussalam, Indonesia (Kalimantan, Sumatra), Malaysia (Peninsular, Borneo)
Aquilaria apiculata Merr	DD	Philippines
Aquilaria baillonii Pierre ex Lecomte	DD	Cambodia, Lao People's Democratic Republic, Viet Nam
Aquilaria banaensis P.H.H.	VU	Viet Nam, Cambodia, Lao People's Democratic Republic**
Aquilaria beccariana Tiegh Indonesia	VU	Brunei Darussalam, Indonesia (Kalimantan, Sumatra), Malaysia (Peninsular, Borneo)
Aquilaria citrinicarpa (Elmer) Hallier f.	DD	Philippines
Aquilaria cumingiana (Decne) Ridl (*Gyrinops cumingiana* Decne)	VU	Malaysia (Borneo), Indonesia (Kalimantan, Maluku, Moluccas, Papua), Philippines
Aquilaria khasiana Hallier f.	CR	India
Aquilaria apiculata Merr	DD	Philippines
Aquilaria parvifolia (Quisumb) Ding Hon (*Gyrinops parviflora*)	DD	Philippines
Aquilaria rostrata Ridl	CR	Malaysia (Peninsula)
Aquilaria rugosa Kiet Kessler	VU	Viet Nam, Cambodia, Thailand
Aquilaria subintegra Ding Hon	DD	Thailand
Aquilaria urdanetensis (Elmer) Hallier f.	DD	Philippines
Aquilaria yunnanensis S.C. Huang	VU	China (Yunnan), Lao People's Democratic Republic, Viet Nam (2019)
Aquilaria filaria (Oken) Merr also as: (*Aquilaria acuminata* (Merr.) Quisumb)	VU	Indonesia (East Nusa Tenggara, Moluccas, Papua), Papua New Guinea, Philippines
Aquilaria sinensis (Lour.) Gilg	VU	China (Fujian, Guangdong, Guangxi, Hainan, Sichuan, Hong Kong SAR, Yunnan), (Lao People's Democratic Republic in plantation only)

Species	IUCN status*	Range states
Aquilaria crassna Pierre ex Lecomte	CR	Bhutan, Cambodia, Lao People's Democratic Republic, Thailand, Viet Nam
Aquilaria hirta Ridl.	VU	Malaysia (Peninsula, Borneo), Indonesia (Kalimantan, Sumatra), Thailand
Gyrinops decipiens Ding Hou	EN	Indonesia (Sulawesi)
Gyrinops versteegii (Gilg)	VU	Indonesia (Nusa Tenggara, Sulawesi, Moluccas, Papua), Papua New Guinea
Gyrinops walla Gaertn.	VU	Sri Lanka
Gyrinops caudata (Gilg)	VU	Papua, Papua New Guinea
Gyrinops ledermannii Domke	EN	Papua, Papua New Guinea
Gyrinops moluccana (Miq.)	EN	Indonesia (Moluccas, Papua), Papua New Guinea
Gyrinops salicifolia Ridl.	EN	Papua, Papua New Guinea
Gyrinops vidalii P.H. HÔ	CR	Thailand, Cambodia, Lao People's Democratic Republic

* CR = critically endangered; EN = endangered; VU = vulnerable; DD = Data deficient, UNK = not listed.
** Uncertain as not reported by Lao People's Democratic Republic, but reported by IUCN.

Agarwood production and trade

The fragrant resin comprising agar develops in the tree heartwood after wounding followed by pathological and non-pathological mechanisms (Ng et al. 1997) as a defense reaction of the plant, and is deposited around the wounds over the years following the injury. The accumulation of the various volatile compounds eventually forms agarwood (Subasinghe and Hettiarachchi 2013). Owing to the high value of agarwood and declining wild populations, there has been an increase in the cost of the wood over time as well as increasing efforts to produce agarwood from planted *Aquilaria* trees. In the commercially cultivated trees, the production of resin is induced by physical penetration of the trunk (wounding) and insertion of a microbial fungal. *Aquilaria* species require up to a decade to reach maturity and most current harvesting techniques, for both wild and cultivated trees, involve destroying the entire tree.

Agarwood is traded as various products and derivatives, including oil, wood, wood chips, flakes, powder, exhausted powder, carvings, and jewelry (see Section 4). High quality wood and oil is primarily used as incense and perfume in Middle Eastern countries (Compton and Ishihara 2004), and agarwood products have been reported as a component of many traditional Ayurvedic remedies in the Indian subcontinent and used in Asian traditional medicines for many ailments including arthritis, infections, fever, and as an analgesic (Barden et al. 2000; Kiet 2003; Lim and Anack 2010). It has also been tested for its anti-carcinogenic properties, including for pancreatic cancer (Dahham et al. 2015). It is clear that the wood has high cultural and medical significance in Asia and the Middle East. Unfortunately, wild populations of all agarwood-producing species have declined considerably over the past 20–30 years (Soehartono and Newton 2001; Chua et al. 2016).

2 Chronology of CITES COP Decisions, discussions on agarwood and NDF development

The severe, long-term overharvesting and subsequent decline in wild *Aquilaria* and *Gyrinops* species resulted in an Appendix II listing by CITES. In Malaysia, for example, Chua et al. (2016) reported that more than 90% of trees with dbh > 30 cm had already disappeared on the Peninsula between 1993 and 2013, primarily due to harvesting, most of it illegal. The CITES listing requires that range states and importers regulate more closely the use of the species, with any material exported requiring a permit. This affords some protection to the wild populations that remain, but also requires international cooperation from buyers.

Appendix II listing

The process leading to the CITES listing began in November 1994, when India proposed that *A. Malaccensis* be included in Appendix II on concern that international demand was threatening the survival of the species. *A. Malaccensis* was listed in 1995 and, starting in 1998, there were discussions at the Plants Committee about protecting more agarwood species. At CITES COP 13 in 2005, Indonesia formally proposed that all *Aquilaria* and *Gyrinops* species be listed in Appendix II. The proposal was approved, resulting in the listing of another 19-plus *Aquilaria* species as well as 8 *Gyrinops* species.

As a consequence of the listing, all countries exporting any agarwood product (with some exceptions–see below) must issue export permits and report the amounts exported to CITES. A country must also indicate to CITES via a "non-detriment finding" (NDF) that agarwood exports will not be detrimental to the survival of the species in the wild.

The listing provides an incentive for countries to conserve remaining stocks and to better manage their populations of agarwood-producing tree species in order to maintain their export industry. It also places an onus on importing countries to try to ensure that any wood that they import has been legally harvested. Some countries have since argued that the list is too inclusive because not all species are endangered, and because not all *Aquilaria* species produce agarwood.

CITES COP Decisions

After the listing of all *Aquilaria* and *Gyrinops* species in Appendix II in 2005, each subsequent CITES COP has made Decisions relevant to agarwood. These Decisions are summarized below.

COP 14, 2007

14.138 (Rev. CoP15) Parties concerned should identify and agree on which agarwood products and quantities should be exempted from CITES controls. Once agreed, Parties concerned should agree which range State will prepare and submit a proposal for amendment of the current annotation for agarwood-producing species to be considered at the 16th meeting of the Conference of the Parties.

14.144 (Rev. CoP15) The Secretariat shall assist in obtaining funding from Parties, intergovernmental and non-governmental organizations, exporters, importers and other stakeholders to support a workshop aimed at strengthening the capacity of Parties to implement agarwood-related Decisions before the 16th meeting of the Conference of the Parties.

14.137 Parties involved in trade in agarwood should, in consultation with the Secretariat, identify funds and produce identification materials for all forms of traded products under CITES control.

14.138 Parties concerned should identify and agree on which agarwood products and quantities should be exempted from CITES controls. Once agreed, Parties concerned should agree which range State will prepare and submit a proposal for amendment of the current annotation for

agarwood-producing species to be considered at the 15th meeting of the Conference of the Parties.

14.140 Parties involved in agarwood trade shall prepare a glossary with definitions that illustrate the content of the amended annotations, the terms used and their practical application during enforcement and border controls. The Secretariat should facilitate the preparation and production of these materials, and strategies for incorporating them in training material.

14.144 The Secretariat shall assist in obtaining funding from Parties, intergovernmental and non-governmental organizations, exporters, importers and other stakeholders to support a workshop aimed at strengthening the capacity of Parties to implement agarwood-related Decisions before the 15th meeting of the Conference of the Parties.

COP 15, 2010

15.95 (Rev. CoP16) Subject to external funding, the Secretariat shall, in cooperation with the agarwood range States and the Plants Committee, organize a workshop to share experiences, discuss management of wild and plantation source agarwood, identify and agree on strategies that balance the conservation and use of the wild populations, while relieving the pressure on these by using the planted material.

15.23 Parties are encouraged:

a) to consider the outputs of the International Expert Workshop on Non-Detriment Findings (Cancun, November 2008) to enhance CITES Scientific Authorities' capacities, particularly those related to the methodologies, tools, information, expertise and other resources needed to formulate non-detriment findings;

b) taking into account Resolution Conf. 10.3, to prioritize activities such as workshops on capacity building to better understand what non-detriment findings are and how to enhance the ways to formulate them; and

c) to report their findings regarding paragraphs a) and b) above at the 25th and 26th meetings of the Animals Committee and 19th and 20th meetings of the Plants Committee.

15.26 Parties are invited to conduct workshops with the participation of appropriate experts on the use of timber species and *Prunus africana*, medicinal plants and agarwood-producing species non-detriment finding guidance in range States concerned with the cooperation of the importing Parties.

15.27 The Secretariat shall:

a) include practical elements for making non-detriment findings for these plant groups in its capacity building workshops, in order to generate feedback from Scientific Authorities to refine the guidelines on making non-detriment findings included in document CoP15 Doc. 16.3;

b) use the external funds offered from interested Parties, intergovernmental and non-governmental organizations, and other funding sources to translate the guidelines into Arabic, Chinese and Russian and to support capacity-building workshops regionally on the use of timber species and *Prunus africana*, medicinal plants and agarwood-producing species non-detriment finding guidance in the range States concerned; and

c) maintain the information up to date and accessible to Parties.

15.94 The Plants Committee shall consider current definitions of artificially propagated plants and how they apply to trees in mixed species plantations and report at the 16th meeting of the Conference of the Parties.

15.95 Subject to external funding, the Secretariat shall, in cooperation with the agarwood range States and the Plants Committee, organize a workshop to discuss management of wild and plantation-source agarwood.

COP 16, 2013

16.155 To facilitate the implementation of the annotation to agarwood producing taxa, based on document CoP16 Inf. 3 and further information available, exporting and importing countries of agarwood producing taxa should produce an identification manual for agarwood products and communicate it to the Secretariat.

16.156 The Plants Committee shall consider the current production systems of tree species including mixed and monospecific plantations and assess the applicability of the current definitions of artificial propagation in Resolution Conf. 10.13 (Rev. CoP15) and Resolution Conf. 11.11 (Rev. CoP15) respectively, and report back at the 17th meeting of the Conference of the Parties.

16.157 The Plants Committee shall monitor the implementation of Resolution Conf. 16.10 Implementation of the Convention for agarwood producing taxa to assess any potential conservation impacts to the long-term survival of agarwood producing species and possible problems arising from the implementation, and shall report on these issues at the 17th meeting of the Conference of the Parties.

16.158 The Secretariat shall, upon receipt of the identification manual mentioned in Decision 16.155 make it available to Parties via the CITES website.

COP 17, 2016

16.156 (Rev. CoP17) The Plants Committee shall consider the current production systems of tree species, including mixed and monospecific plantations, and assess the applicability of the current definitions of artificial propagation in Resolution Conf. 10.13 (Rev. CoP15) and Resolution Conf. 11.11 (Rev. CoP15) respectively, and report back at the 18th meeting of the Conference of the Parties.

16.157 (Rev. CoP17) The Plants Committee shall monitor the implementation of Resolution Conf. 16.10 (Implementation of the Convention for agarwood-producing taxa) to assess any potential conservation impacts to the long-term survival of agarwood-producing species and possible problems arising from the implementation, and shall report on these issues at the 18th meeting of the Conference of the Parties.

17.194 Range, transit, consumer, and producer Parties of agarwood products are invited to compile and publish identification manuals on agarwood products, taking into consideration the updated version of the Glossary provided in the Annex to document PC22 Doc. 17.5.3, and any further updated version, if appropriate. They are encouraged to distribute these identification manuals as training material to management and enforcement officials.

17.195 Subject to available funding, the range States shall generate and compile biological and ecological data as well as information on the harvest, trade and management of agarwood-producing species in the wild. Range states are requested to report this information at the regional agarwood workshop referred to in Dec. 17.197, and agree on regional priorities to ensure the survival of populations of agarwood-producing species in the wild.

17.196 The range States are invited to develop policies to encourage the sustainable use of and trade in parts and derivatives of artificially propagated agarwood-producing trees.

17.197 Subject to external funding, the Secretariat, in cooperation with agarwood range States and the Plants Committee, shall organize a regional workshop to: continue the work of the Asian Regional Workshop on the Management of Wild and Planted Agarwood Taxa, hosted by the Government of India in Guwahati, Assam, India, from 19 to 23 January 2015 with an emphasis on how range States can cooperate to ensure the long-term survival of agarwood-producing species in the wild through agarwood plantation programmes that integrate forest recovery programmes; and strengthen the agarwood network for sharing information on planting stocks, management, technologies, harvest and trade.

17.198 The Secretariat will report to the Plants Committee meeting on the implementation of Decisions 17.195 and 17.197 prior to the 18th meeting of the Conference of the Parties to CITES.

17.199 The Plants Committee will consider the report of the Secretariat submitted in accordance with Decision 17.198 and report accordingly to the 18th meeting of the Conference of the Parties.

17.200 Consumer and trading countries of agarwood are encouraged to contribute financially towards the *in situ* conservation of wild populations of agarwood-producing species in range States and foster cooperation between *in situ* conservation programmes and the fragrance industry for the promotion of the conservation and sustainable use of agarwood-producing species.

COP 18, 2019

18.203 The Plants Committee shall:

a) monitor the implementation of Resolution Conf. 16.10 on *Implementation of the Convention for agarwood-producing taxa* to assess any potential conservation impacts to the long-term survival of agarwood-producing species and possible problems arising from the implementation, by:

i) developing a questionnaire on potential conservation issues in the implementation of Resolution Conf. 16.10 on *Implementation of the Convention for agarwood-producing taxa* to be circulated to the Parties through a Notification, and analysing the responses received;

ii) examining available trade data; and

iii) analysing available data on the conservation status of agarwood-producing species; and

b) report findings and recommendations to the 19th meeting of the Conference of the Parties and advise on the need for a study to further assess impacts of harvest, management and trade in agarwood products on the conservation of agarwood-producing species in the wild.

18.204 The Secretariat shall assist the Plants Committee in the implementation of Decision 18.203.

CITES COP Resolutions

In addition to the Decisions listed above, there is also one CITES COP resolution pertaining to agarwood species: Resolution Conf. 16.10[2]. The resolution deals with several issues, including that agarwood from plantations could not under the existing rules be considered as produced "under controlled conditions" and "artificially propagated". Following from this resolution, however, it was later agreed that plantation agarwood does meet the requirements to be considered as artificially propagated. The resolution also requested that Parties establish registration systems for plantations and exporters, and asks that Parties use the CITES agarwood glossary adopted by the Plants Committee at its 20th meeting as a means to standardize terminology.

[2] https://cites.org/eng/res/16/16-10.php

A report prepared for CITES on the implementation of Resolution Conf. 16.10 summarized work pertaining to agarwood for the twenty-second meeting of the Plants Committee (PC 22) in 2015.[3] The report noted that the Asian regional workshop on the management of agarwood was held in 2015 in Assam, India and that the meeting report was publicly available.[4]

A glossary of agarwood products was prepared as requested by the CITES COP Management Authorities of Kuwait and China and made available on the CITES website.[5] The glossary, however, has not been considered suitable by all Parties and requires further work.

COP 18 Doc. 65 also provided an update with respect to Resolution Conf. 16.10.[6] It provided the same report that went to the Plants Committee, but also included a report from a subsequent agarwood meeting in 2018, in Indonesia: the "Second Regional Workshop on the Management of Wild and Planted Agarwood Taxa". The workshop resulted in a large number of recommendations for the management of wild and plantation agarwood trees.[7]

CITES Plants Committee discussions

In 2015, the twenty-second meeting of the CITES Plants Committee (PC 22) noted that existing guidance did not address the definitions for "artificially propagated" agarwood (Resolution Conf. 16.10), grafts (Resolution Conf. 11.11 [Rev. CoP15]) or trees grown in monospecific plantations (Resolution Conf. 10.13 [Rev. CoP15]). It also noted the need to monitor progress on the implementation of Resolution 16.10.

Following from the CITES agarwood meeting in Assam, India, PC 22 recommended that Parties:

- compile biological and ecological data and information on illegal harvest;
- develop policies for sustainable use of artificially propagated agarwood;
- organize a regional workshop to assess ways to ensure survival of agarwood species; and
- contribute to improving the agarwood glossary.

PC 23, held in 2017, asked that the glossary be made available via the CITES website.

A year later, PC 24 asked CITES to send a questionnaire on agarwood trade to Parties and to analyze the gathered data. The questionnaire was sent to relevant Parties in 2020. However, the Secretariat only received eight responses, as reported to PC 25, which highlighted the following points:

- There is no certainty in any country about the status of wild populations of agarwood species trees.
- There is no agreement on the issue of whether "assisted production" could complement the concepts relating to "artificial propagation" as defined in Resolution Conf. 16.10. Resolving this issue needs further discussion.
- Countries do not have a method to distinguish between wild and planted agarwood raw products and this remains a problem in trade.
- Not all countries have established a registration system for exports.

[3] https://cites.org/sites/default/files/document/E-Res-16-10_0.pdf
[4] http://www.itto.int/files/user/cites/outputs/Report%20of%20Asian%20Regional%20Workshop%20on%20Agarwood20Feb.pdf
[5] https://cites.org/sites/default/files/notif/E-Notif-2016-041_0.pdf
[6] https://cites.org/sites/default/files/eng/cop/18/doc/E-CoP18-065.pdf
[7] https://cites-tsp.org/wp-content/uploads/2020/02/CITES-Tree-Species-Programme-Regional-Meeting-for-Asia-and-Second-Regional-Workshop-on-the-Management-of-Wild-and-Planted-Agarwood-Taxa-25-to-29-June-2018-Yogyakarta-%E2%80%93-Indonesia-%E2%80%93-Minute.pdf

- There is no agreement that the current glossary of products is sufficient, owing to varying interpretations of some words and uncertainty regarding its value for enforcement.
- Distinguishing exhausted from non-exhausted powder is a problem at import borders.
- NDF guidance could be updated.
- Wild-collected agarwood plant material (e.g. saplings) can be exported as "artificially propagated" specimens (source code "A") under the provisions of Resolution Conf. 16.10. In order to effectively regulate such specimens in trade, and to ensure that wild agarwood plant material is obtained in a manner that is non-detrimental to species in the wild, it may be more appropriate to treat and trade such specimens as derived from "assisted production" (source code "Y") as defined in Resolution Conf. 11.11 (Rev. CoP18).

PC 24 also noted the problems with implementing Resolution 16.10 and requested the Secretariat, based on the responses to a questionnaire, to perform an analysis of available trade data, and on available data regarding conservation status, and to commission a study if required to assess any potential conservation impacts.

PC 25, held online in 2021, recommended to consider further potential revisions to Resolution Conf. 16.10 on the implementation of the Convention for agarwood-producing taxa, taking into account other relevant Resolutions, including Resolution Conf. 10.13 on Implementation of the Convention for tree species, as appropriate; and to formulate appropriate recommendations regarding the agarwood glossary and the agarwood NDF guidance.

Recent discussions at the Plants Committee about agarwood have related mostly to regulatory issues, such as the status of planted and wild species and aspects of the various products, including using a source code 'Y' instead of the special provisions for trade for artificially propagated agarwood. PC 25 noted the need for identification of materials from wild versus planted stock, and the need for capacity building and guidance on legal acquisition findings, including on the chain of custody, with regard to specimens of agarwood-producing taxa.

Most recently, the working group on annotations reviewed Annotation 14 (which specifies products covered by the agarwood listing) in March 2022.

> Current CITES Annotation 14:
> All parts and derivatives [derived from *Aquilaria* and *Gyrinops*] are listed under CITES~~]~~ 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.

The working group had previously considered that, for conservation reasons, the term "exhausted powder" should be retained to differentiate it from non-exhausted agarwood powder.[8] More recently, the working group stated that "further review of the appropriateness and practical challenges resulting from the implementation of Annotation 14 should be included in any new Decisions directed to the Standing Committee for further work during the intersessional period

[8] https://cites.org/sites/default/files/eng/com/sc/66/E-SC66-25.pdf

between COP 19 and COP 20."[9] There was continuing concern that "exhausted agarwood powder may be difficult to enforce in trying to distinguish it from original [unexhausted] powder". However, the Plants Committee's *Aquilaria* working group and experts at the Royal Botanic Gardens, Kew have suggested that gas chromatography-mass spectrometry analysis is an effective tool for identifying and quantifying materials present in a wood sample, and that this technology could be used to determine the percentage of oil within agarwood powder, possibly providing a foundation for differentiating between exhausted and non-exhausted powders. There are also some grammatical issues regarding the translation of Paragraph (f) of Annotation 14 into Spanish and French, relating to different punctuation that need to be resolved for universal clarity.

Non-detriment findings

Under CITES, NDFs must be developed and approved prior to the export of any Appendix II plant species. The term "export" for the purposes of CITES only applies to the trade of specimens from their country of origin. "Re-export" applies to the trade of specimens originating from a country other than the exporting country. In such instances, specimens only require a "re-export certificate". "Country of origin" is defined as the country in which a specimen was taken from the wild or artificially propagated.

CITES has provided range states with guidance for developing an NDF. But while there is good information on the methods, there is no one standard procedure. To establish an export quota, an NDF must show that the export of materials of a listed species will not harm the native population of that species. For trees, an NDF is basically a study of population, growth, and sustainable harvesting that provides information on what a safe annual allowable cut might be while sustaining the wild population within a country. An NDF should include a scientific review of available information on the population status, distribution, population trend, harvest and other biological and ecological factors, as appropriate, and trade information relating to the species concerned. The case of agarwood is different from other CITES-listed tree species that are harvested for their timber, because the agarwood product is found in a low percentage of wild trees (estimates range from 1% to 10% (La Frankie 1994, Oldfield 1998, Chhipa and Kaushik 2017)), making the development of an NDF methodology more challenging. Further, while agarwood can be removed from trees without harvesting, this is rarely done.

A workshop on developing NDFs for any species listed under CITES was held in Mexico in 2008, and produced a support document.[10] CITES has also produced several other guidance documents on developing NDFs, including for agarwood species.[11] As recently as COP 18, however, Parties asked for further assistance on developing an NDF (with a specific focus on agarwood), including a gap analysis, a further workshop and additional research.[12] This indicates that there remains some uncertainty among Parties about how an NDF should be prepared for agarwood species and the data required.

The CITES Scientific Authority for a given country is responsible for developing NDFs for that country. CITES also requires Scientific Authorities to monitor the export of specimens of Appendix II species. To carry out monitoring, it is important that Scientific Authorities work closely with the

[9] https://cites.org/sites/default/files/eng/com/sc/74/E-SC74-81.pdf
[10] http://www.conabio.gob.mx/institucion/cooperacion_internacional/TallerNDF/taller_ndf.html
[11] https://cites.org/eng/node/129711, https://cites.unia.es/cites/file.php/1/files/03.pdf, https://cites.org/sites/default/files/eng/com/ac-pc/ac31-pc25/E-AC31-14-01-PC25-17.pdf, https://cites.org/sites/default/files/common/com/pc/17/X-PC17-Inf-04.pdf, https://cites.org/sites/default/files/common/cop/16/inf/E-CoP16i-11.pdf
[12] Decision 18/132-134

CITES Management Authority for the country as well as customs and other relevant law enforcement agencies on species identification and control of the chain of custody. An effective monitoring system is essential to ensure that exports stay within limits laid out in an NDF and do not become detrimental to the survival of the species in the wild.

Despite the available guidance, it appears that most countries lack the capacity, funding, political will, and/or sufficient data to develop an NDF. CITES and ITTO have tried to rectify this problem, in part, through the various iterations of their cooperative ”endangered tree species programme” (currently housed at CITES as the “CITES Tree Species Programme”—see Box 1). The programme has provided funding to some countries, notably Indonesia and Malaysia, to develop the information required to produce an NDF. Among exporting countries, the following have established NDFs for agarwood: Indonesia (2009), Malaysia (preliminary in 2008, updated 2011, 2013), Thailand (for *A. crassna,* 2016), and India (2021). The Indian and Thai NDFs were not available for review in this report, the latter because it has not been translated. The Lao People's Democratic Republic is currently in the process of developing an NDF based on new census data. Information made available at the 2022 CITES agarwood workshop indicated that the NDF for India contains data on which the country’s export quota is based.

The NDF from Indonesia dated 2009 provided estimated populations of *A. malaccensis* and *A. filaria* based on data from 2001 to 2003, broken down by province or sub-province. For example, the density of trees was estimated at 10/ha in West Kalimantan (an area with 8.3 million ha of forest) which would translate to a population of 83 million *Aquilaria* trees. However, most published reports of tree populations (including for Indonesia) suggest that a more normal tree (dbh > 10 cm) density is less than 1–2 trees/ha (e.g. Oldfield et al. 1998; Soehartono and Newton 2000; Chua 2008; Blanchette et al. 2015). For example, Soehartono and Newton (2000), indicated a tree density of just 1.17 $\pm$ 1.09/ha for *Aquilaria* spp. in upland Kalimantan forests. These data suggest possibly a rather large overestimate of the population in the 2009 Indonesia NDF, if the 10 tree/ha reported estimate is for trees of dbh > 10 cm (which is not clear in the document annex). Unfortunately, the NDF for Indonesia has not been updated, despite a very large export quota of more than 500 000 kg for each of the 13 years since the NDF was produced. There have been, however, several recent publications from Indonesia that provide local population data, as reported from the 2022 CITES agarwood workshop. None of these reports, however, sampled large areas and few trees were reported.

The NDF for Malaysia (Chua 2008) is also out of date as a contemporary management tool. However, Malaysia has been conducting population censuses for *Aquilaria* with the last one completed in 2013. These censuses form the basis for an NDF and while an updated document is lacking, the harvesting and export quotas are based on some data. In fact, the Malaysia export quota has declined from a high of 200 000 kg in 2015 to just 50 000 in 2022. In addition, Malaysia has information on its plantation resources and has seen a large increase in plantations after 2002 (See Section 5). The Malaysian NDF sets out the rules by which agarwood can be harvested, the fees required, the process for the registration of products, and how much wood can be harvested.

3 A review of CITES trade data

The CITES database

Regrettably, most governments do not provide statistics on the production or harvest of agarwood. Consequently, the CITES export database is the only source of information about global trade patterns. The CITES database contains reports of agarwood species exports that record the genus and (sometimes) species by country, year, type of product, and (usually) amount of product.

The products recorded include: derivatives, chips, extract, live specimens, logs, oil, powder, sawn wood, specimens, wax, carvings, timber, jewelry, timber pieces, stems, medicines, leaves, veneer, seeds, dried plants, boxes, bottles, and wood products. The amounts are reported in m^3, g, or kg for most wood products; kg, ml, or litres for oil and extract; and number of specimens, g, or kg for plants and stems.

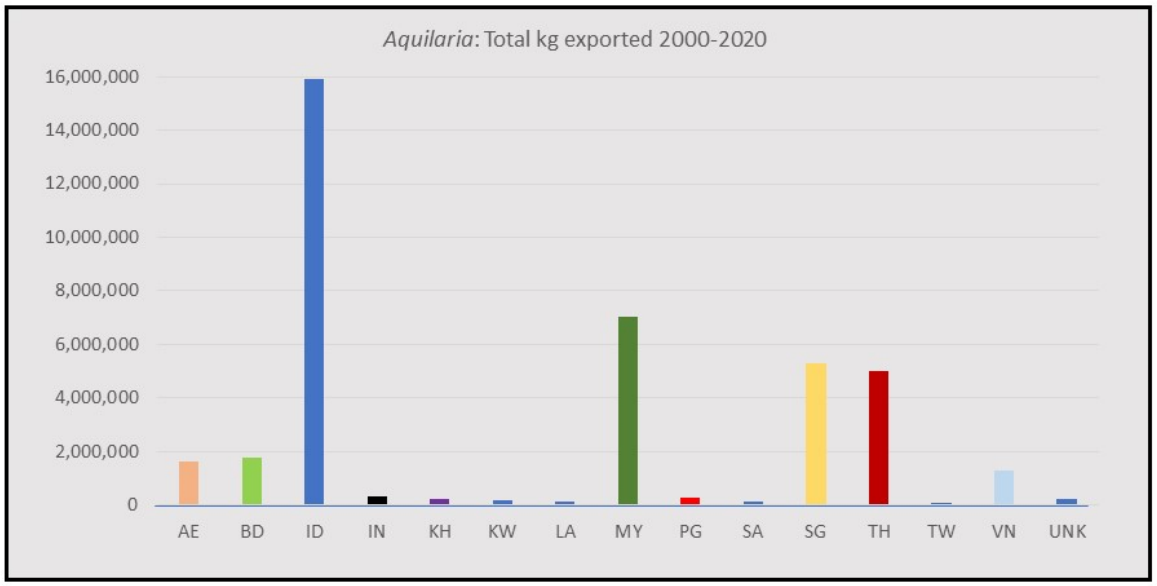
However, a large number of CITES records do not include units for the exported good. All countries have some "no-unit" entries, but most are from Malaysia and, of these, most are recorded as wild stock, indicating that the amounts recorded for wild stock exported are probably underestimates. In addition, between 2000 and 2020, more than 236 000 kg were recorded as exported product but with no known exporting country (recorded as XX or XY in the database). In some cases, only the number of "pieces" exported is recorded. There is thus a clear need for standardized methods for reporting product types and amounts in order to make the data more accurate and easier to interpret.

Despite these shortcomings, the vast majority (more than 95%) of exports in the database were recorded with amounts in m^3, kg, or g, making it possible to summarize that information, understand which countries are significant exporters and importers of agarwood, and identify trends over time (Figures 2 to 9). Indonesia, Thailand, and Malaysia are the three major exporting countries of original product, while several countries or regions import raw agarwood and refine it into more finished products and then re-export the material or keep it for local markets. The latter group includes the United Arab Emirates, Saudi Arabia, Kuwait, Taiwan POC, and Singapore (which has *Aquilaria* trees but does not harvest them). The main exported products from Indonesia and Malaysia are chips, powder, sawn wood, and logs. The main re-exported products include oil, chips, powder, and wood. Oil is by far the most expensive product and most oil is produced by (largest exporters first) the United Arab Emirates, Thailand, Malaysia, and India.

Leading exporters

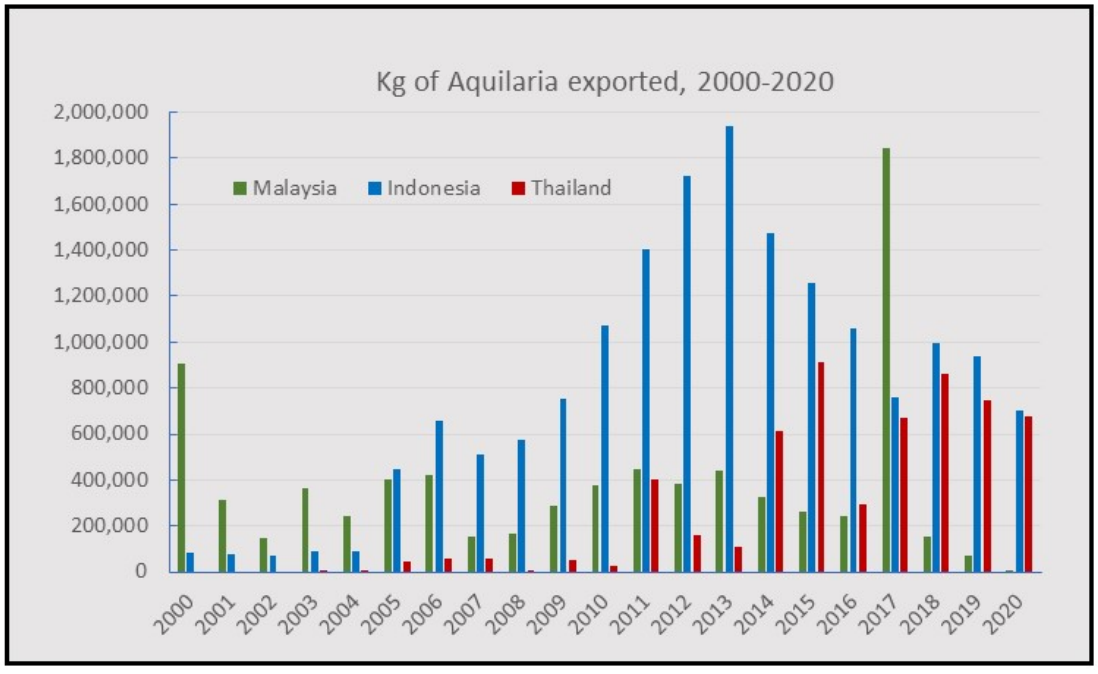
Most *Aquilaria* is exported from Indonesia, Malaysia, and Thailand (Figure 2), with Singapore a significant re-exporter. Recent export patterns have been similar for Malaysia and Indonesia, with the amount produced by Indonesia rising significantly after 2008, and then falling again after 2013 (Figure 3). The exceptionally high figure for Malaysia in 2017 may be due to a reporting error (such as the use of m^3 instead of kg to measure a shipment). The data for Thailand indicates little agarwood was exported prior to 2011, followed by a large increase to a more or less consistent level after 2013. The rise in exports from Thailand corresponds to the increasing maturity of its relatively young plantations. Cambodia, on the other hand, exported a total of more than 315 000 kg of wild agarwood between 1993 and 1998, and then nothing for a decade until small amounts were recorded again starting in 2008. An exception was 2016, when 200 000 kg was exported (Sinly et al. 2022). The same study suggests that some agarwood has been exported from Cambodia without permits.

Figure 2: Major exporters of *Aquilaria* agarwood, showing total exports (of all forms of product reported in m^3, grams, or kg) between 2000 and 2020 from countries/provinces exporting at least 50 000 kg.



Key: AE = United Arab Emirates, BD = Bangladesh, ID = Indonesia, IN = India, KH = Cambodia, KW = Kuwait, LA = Lao People's Democratic Republic, MY = Malaysia, PG = Papua, SA = Saudi Arabia, SG = Singapore, TH = Thailand, TW = Taiwan POC, VN = Viet Nam, UNK = Unknown

Figure 3: Annual *Aquilaria* agarwood exports (all forms of product reported in m^3, grams, or kg) from Malaysia, Indonesia and Thailand between 2000 and 2020.



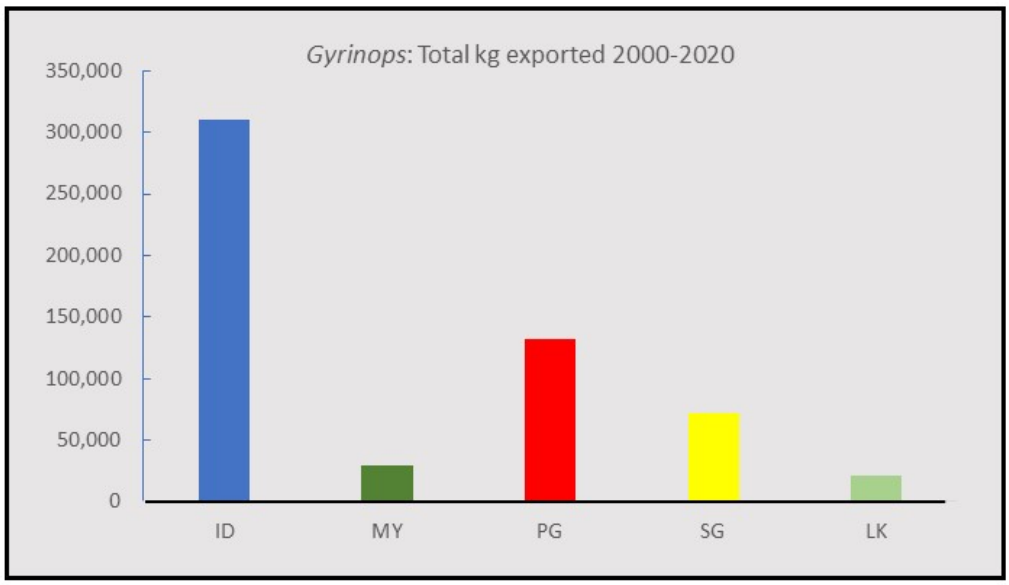
The trade in *Gyrinops* agarwood is considerably smaller than that in *Aquilaria* agarwood (492 778 kg of *Gyrinops* vs. 19 681 624 kg of *Aquilaria* from all source countries between 2000 and 2020). The main *Gyrinops* agarwood exporters are Indonesia, Papua (recorded separately), Malaysia (re-

export[13]), and Sri Lanka (Figure 4). All countries export *Gyrinops agarwood* primarily as chips. The major producers of agarwood oil from *Gyrinops species* are Singapore and Sri Lanka.

Leading importers

There are many importing countries for agarwood, including in Africa, Asia, North America, and Europe. The list has expanded as the cosmetics industry has become more interested in agarwood scents. The main importers of *Aquilaria* include the United Arab Emirates, Saudi Arabia, Singapore, and Taiwan POC (Figure 5). While the Middle East is the biggest market for agarwood, France, the United Kingdom and especially China have all increased imports since 2010 (Figures 6 and 7). *Gyrinops* is primarily imported into Saudi Arabia and Singapore (Figure 8).

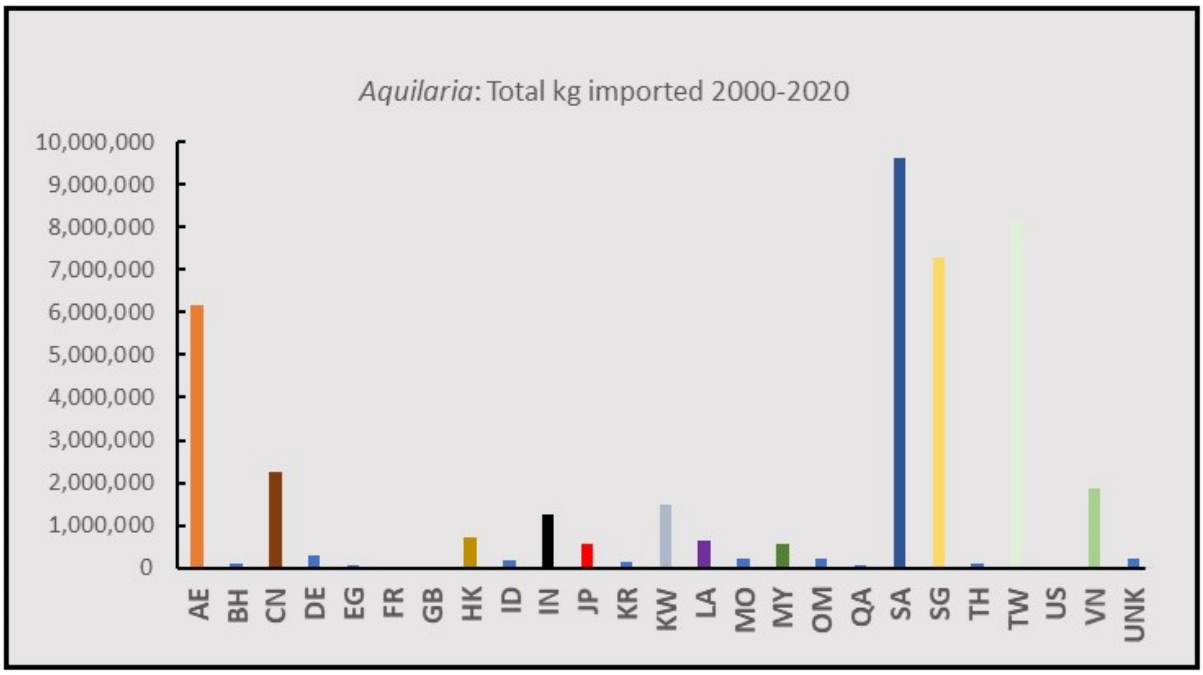
Figure 4: Major exporters of *Gyrinops* agarwood, showing total exports (all forms of product reported in m^3, grams, or kg) between 2000 and 2020 from countries/provinces exporting at least 20 000 kg.



Key: ID = Indonesia, MY = Malaysia, PG = Papua, SG = Singapore, LK = Sri Lanka

[13] No records for *Gyrinops* exist for Malaysia; these data may be in error but otherwise must be re-export (K.H. Lau, pers. comm.).

Figure 5: Major importers of *Aquilaria* agarwood (all forms of product reported in m^3, grams or kg), showing total imports between 2000 and 2020 for countries importing at least 20 000 kg. (The value for China is an underestimate because, in several years, large amounts of "logs" or "timber" were imported with no units recorded.)



Key: AE = United Arab Emirates, BH = Bahrain, CN = China, DE = Germany, EG = Egypt, FR = France, UK = United Kingdom, GB = Great Britain, HK = Hong Kong SAR, China, ID = Indonesia, IN = India, JP = Japan, KR = Republic of Korea, KW = Kuwait, LA = Lao People's Democratic Republic, MO = Macau SAR, MY = Malaysia, OM = Oman, QA = Qatar, SA = Saudi Arabia, SG = Singapore, TH = Thailand, TW = Taiwan POC, US = United States of America, VN = Viet Nam, UNK = Unknown

Figure 6: Annual *Aquilaria* agarwood imports into France and the United Kingdom from 2000 to 2020, reflecting increased use of agarwood in the cosmetics industry in some developed countries.

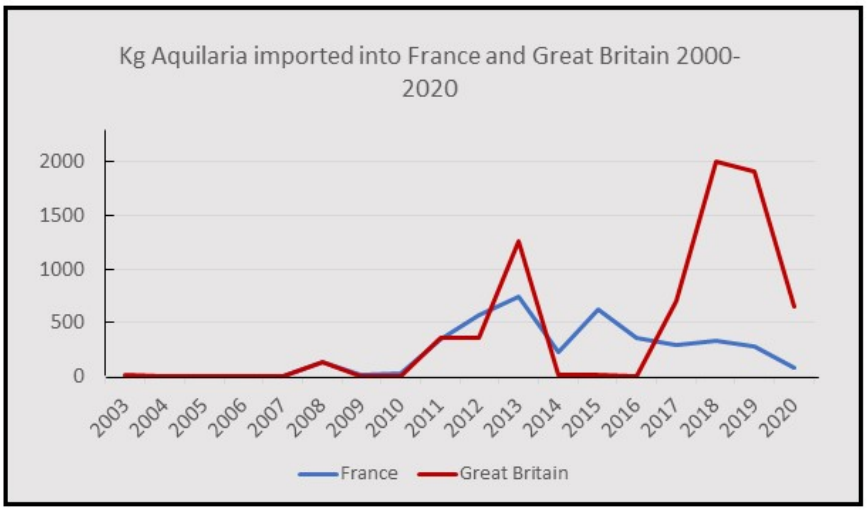


Figure 7: *Aquilaria* imports into mainland China from 2000 to 2020. (Note: numbers are underestimates for several years when large amounts of "logs" or "timber" were imported with no units recorded.)

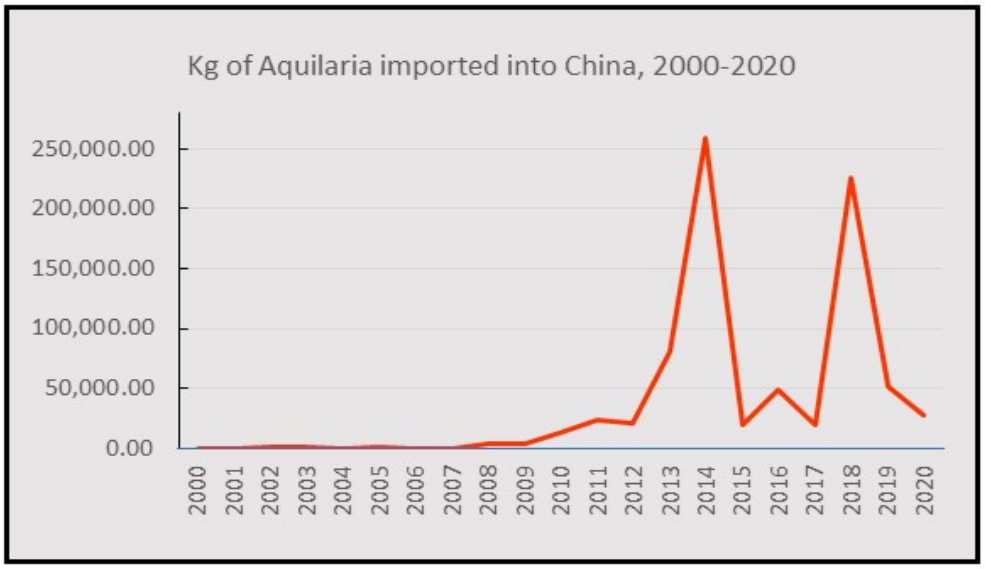
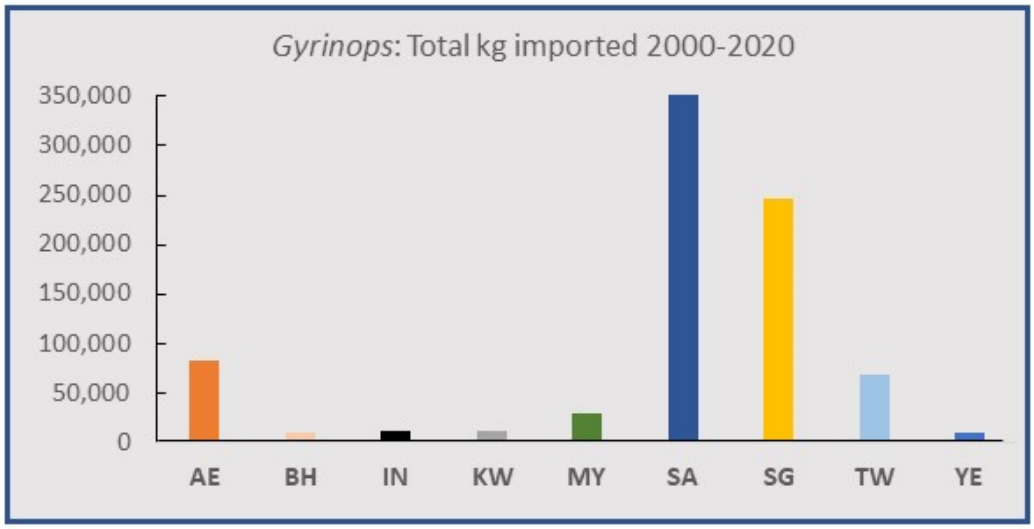


Figure 8: Major importers of *Gyrinops* agarwood (all forms of product reported in m^3, grams, or kg), showing total imports between 2000 and 2020 into countries/provinces importing at least 20 000 kg.



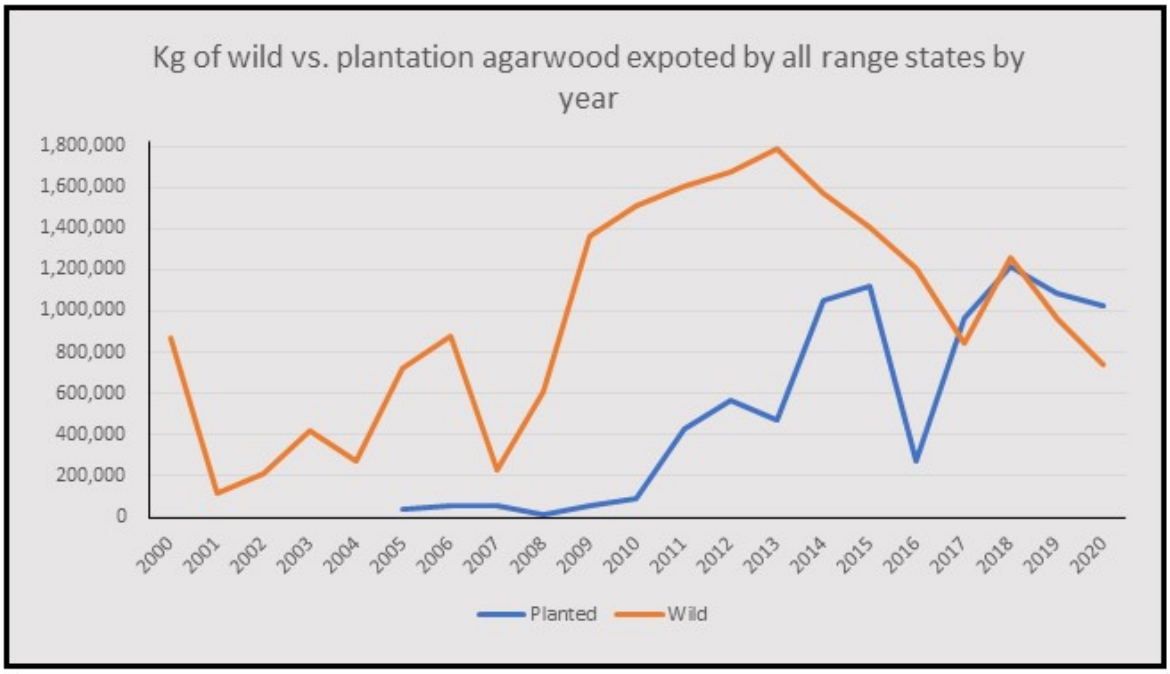
Key: AE = United Arab Emirates, BH = Bahrain, IN = India, KW = Kuwait, MY = Malaysia, SA = Saudi Arabia, SG = Singapore, TW = Taiwan POC, YE = Yemen

The rise of plantation agarwood

The ratio of wild to plantation-sourced *Aquilaria* agarwood in the CITES export data has changed over time (Figure 9). Up to 2005, only *A. malaccensis* was listed in Appendix II and so, until then, all recorded exports were of that species. Following the listing of all *Aquilaria (*and *Gyrinops)* species, there was a large increase in the reported export of wild stock, especially over the period 2008–2013, followed by a large decline in exports beginning in 2014. A second decline since 2018 has brought exports in 2020 to below 800 000 kg/yr, or less than half of the 2013 peak. At the same time, exports of plantation agarwood—first recorded in 2005—have risen substantially since 2010. In 2020, they totalled more than 1 million kg and appear to have surpassed those of wild agarwood.

There is also some contradictory information about wild and plantation-sourced material. Pasaribu et al. (2021) state that no plantation agarwood had been exported from Indonesia up to 2020, but the CITES database indicates that small amounts of planation agarwood have been exported since 2013. Nevertheless, less than 2% of Indonesia's exports were from plantations during 2019 and 2020. While Malaysia also reported less than 2% of its exports as coming from plantations in 2019, most of the just 8 400 kg exported in 2020 according to CITES data was from plantations.

Figure 9: Total wild and plantation *Aquilaria* exports 2000–2020 (all products reported in m^3, g, or kg).



The CITES database also enables a comparison file, which shows how much product was imported by a country with the amount from the exporting country. While these data should theoretically match, generally they do not. Finally, comparing total global exports and imports for *Aquilaria shows that* there were 6 273 402 kg more recorded as imported than was reported exported in the 20-year period, indicating that roughly 300 000 kg/yr are not being reported as exported. Similarly, for *Gyrinops*, the data indicated that about 20 000 kg/year are not being recorded as exported. Lim and Noorainie (2010) also illustrated this issue by finding huge differences between Malaysian customs export data and the data recorded in the CITES database for all years from 1995 to 2002, including some years where the difference was of more than 1 million kg of agarwood.

Overall, however, the CITES database for agarwood remains useful for illustrating trends in the main exporting and importing countries and also trends over time in amounts and product types. Unfortunately, the many inconsistencies in reporting units, different names for products, exports to and imports from unknown countries, and the substantial differences between imported and exported amounts, indicate that there is a high level of inaccuracy in the reporting system. These issues need to be addressed by CITES to improve clarity of the information for these two tree species and to enable better protection for wild populations. Suggestions for improvement to the

database include: standardized units, standardized product types, direct reporting by country customs agencies to CITES, and an annual audit of data by CITES.

Voluntary quotas

CITES also maintains a database of voluntary agarwood quotas as reported by the Parties. Quotas are typically an annual allowable cut set by a country's Scientific Authority and recommended to its Management Authority. As noted, many countries lack the capacity and the data required to produce a meaningful quota or an NDF report, introducing uncertainty into the management of wild stocks. There are recorded quotas for four exporting countries for *Aquilaria* agarwood, including: India (for 2022–2024, of 25 000 kg, including 1 500 kg of oil); Indonesia (for 2006–2021, of 30 000–178 482 kg; in 2021 the quotas were 101 000 kg for *A. malaccensis*, 490 010 kg for *A. filaria*, and 3 000 kg for *G. versteegii*); and Malaysia (for 2012–2022, of 30 000–200 000 kg; in 2022, the quotas are 50 000 kg for Peninsular Malaysia and 5 000 kg for Sarawak). Quotas for the Lao People's Democratic Republic have been recorded since 2020 and increased for 2022 for *A. crassna* to 7 600 m^3 of logs, 134 000 kg of chips, 1 910 litres of oil, and 42 000 kg of powder. Export quotas have been exceeded in some years, although Indonesia exported less than its proposed quota from 2014 onward, according to its presentation at the 2018 CITES agarwood workshop. For *Gyrinops*, there were only quotas from Indonesia, for the years 2008–2016, ranging from 5 000 kg to 520 740 kg (where the higher figure also included *A. filaria*). In some years, the quotas were allocated to specific products, while in most years they were general. Overall, despite concern for wild populations, very few range states have developed and applied export or harvest quotas and those that have developed quotas have done so in the absence of good data on populations of these species.

4 Agarwood products and their trade

Forms of agarwood

Agarwood is sold in many forms. The most common raw export products are chips, powder, sawn wood, and logs. Modified agarwood products include oil, exhausted powder, medicines, perfumes and cosmetics, incense (joss), carvings, and jewelry.

Several destination markets exist for agarwood, including the Middle Eastern market for oil, high quality chips, and lesser quality products for bakhoor, and the Asian market for high quality incense products, exhausted powder used for making incense joss sticks, small solid wood products (including prayer beads and small sculptures), and medicinal products. In addition, there is a growing market in the European Union, the United Kingdom, and the United States of America for agarwood oil for use in cosmetics and perfumery (UNCTAD 2017).

Agarwood fragrances are considered a symbol of a high standard of living in Middle Eastern and Arab countries and the market for luxury and premium goods in that region continues to grow. Indonesia has produced some novel agarwood products, of which black magic wood (BMW) has become popular. BMW is produced by impregnating (non-agarwood) wood chips with a mixture of agarwood resin and low-grade agarwood oil in a high-pressure boiler. BMW (known in Arabic as "oud sana'i") now has a market in the Middle East, especially among middle-class consumers in the United Arab Emirates. BMW is a cheaper alternative to agarwood and sells for about USD 400/kg (Turjaman 2022).

The majority of reported exports are of *A. malaccensis* and *A. crassna* (total 66%), but 24% was not attributed to any species, based on the CITES database (Figure 10). Given that CITES is a "species' convention", the high percentage of unknown species is rather disappointing, indicating some

disregard among exporters for proper detail in permitting. The other six *Aquilaria* species contributed only minor amounts of the agarwood in trade. For *Gyrinops*, the majority was attributed to *G. versteegii* and *G. walla*, with 26% not recorded by species (Figure 11).

Figure 10: Shares of individual *Aquilaria* species among total exports of agarwood products from all range states from 2000 to 2020. Numbers following species names in the key are actual % of the total exported weight.

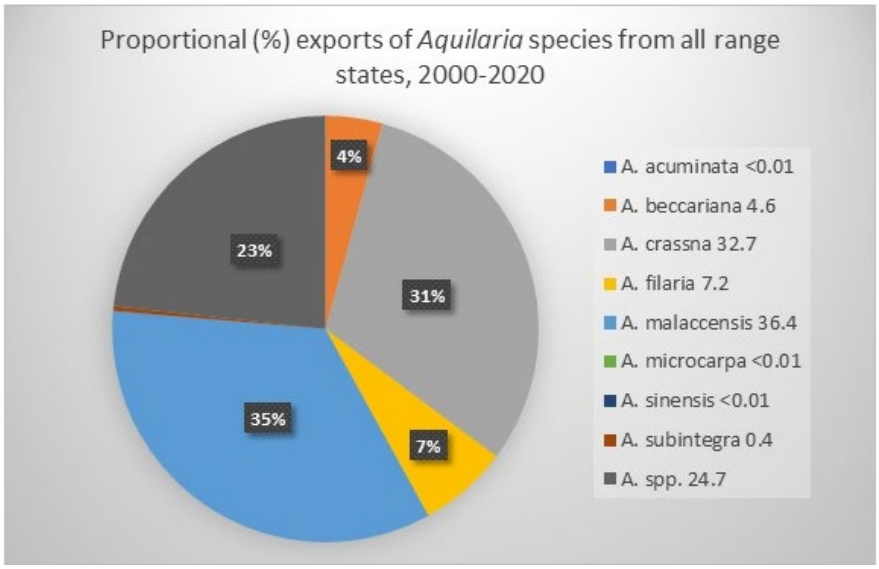
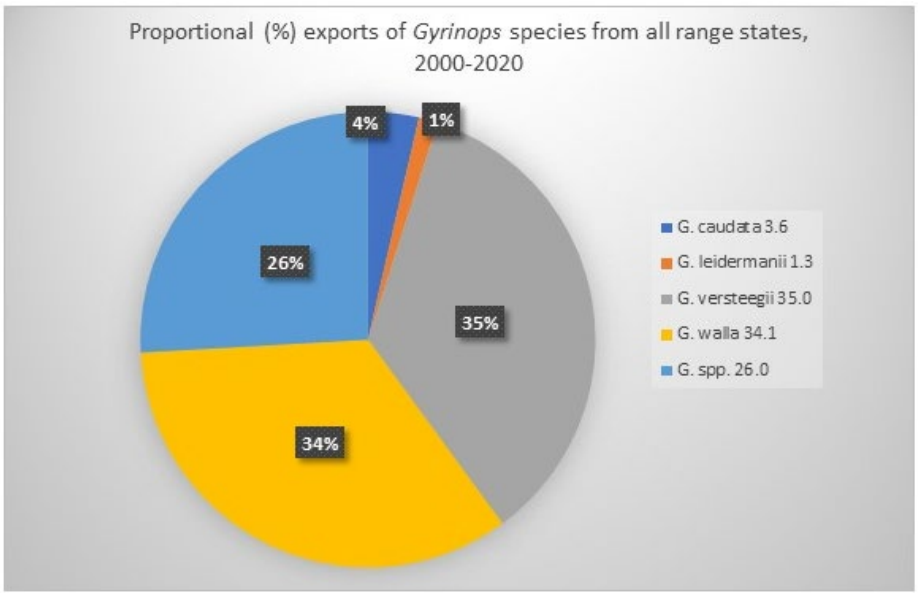


Figure 11: Shares of individual *Gyrinops* species among total exports of agarwood products from all range states from 2000 to 2020. Numbers following species names in the key are actual % of the total exported weight.



Product grading

No standard biochemical parameters have been determined to define and grade agarwood, and the combination of its various constituent compounds can vary between different samples from the same tree. Nevertheless, the value or grade of agarwood product has long been subjectively

and comparatively graded by experts, based on colour, odour, specific gravity, and resin content, and prices can vary greatly for the same product depending on the grade (Naziz et al. 2019). Agarwood experts apparently can even differentiate between the scent profiles of agarwood oil (also known as oud oil) from wild-sourced stock from particular regions. The quality and value of extracts are dependent both on the skills of the manufacturer and the quality of the source product.

Agarwood grading in the marketplace often uses a lettering system (A to D) combined with descriptive terms (such as super, supreme, deluxe, +/-) and/or a numerical classification (1–5) to distinguish quality. There is no commonly accepted standard, even within individual countries or states, let alone across the industry. For example, it is possible to find agarwood graded as Super Deluxe, Super Double, Super, A, or oil graded as AAA, AA, A+, A, and A1 (Oud Oil Trading 2022) There are different grading systems in the various exporting countries. For example, Malaysia uses a 12-grade system, while Indonesia uses a 9-grade system. China has published its own guide for grading agarwood (Anonymous, 2017).

Various quantitative methods involving gas chromatography and mass spectrophotometry have also been used to distinguish among grades (e.g. Wang et al. 2021). But the industry still lacks a global grading standard for agarwood based on quantifiable indicators.

Oil extraction

While raw agarwood of high quality is often burned as whole chips for its fragrance, lesser quality wood is generally reserved for oil extraction. Oil extraction techniques are considered proprietary and often closely guarded by the various manufacturers, primarily because proper techniques can substantially increase both quality and yield. One litre of agarwood oil requires about 144 kg of wild-source chips to produce, making the oil a very expensive product (Lim et al. 2022). Some extraction techniques and the use of plantation stock require even more wood. For example, in Cambodia, producing a litre of oil requires 1 000 kg of young plantation wood of *A. crassna* (Sinly et al. 2022).

Oil extraction usually involves one of three main methods: hydro-distillation, steam distillation, or supercritical carbon dioxide extraction. All the processes use dried chipped wood that is ground into a pulp and boiled in a still. Hydro-distillation is the oldest and most labour-intensive method of the three and involves soaking the wood, boiling it in water and removing the oil from the water surface. Yields can be as low as 0.1%. Pressurized steam is faster but risks scorching the wood and may also produce substances that can reduce the quality of the final product. The use of carbon dioxide as a solvent is uncommon. While it has the potential to produce higher yields, the process can also result in the extraction of derivatives that can impact on quality. Other techniques are currently being studied to produce higher yields and improve the quality of the oil, including solid liquid extraction, microwave-assisted extraction, spinning band distillation, ultrasonic assisted steam distillation, supercritical fluid extraction, and ultrasonic assisted hydro-distillation (Lim et al. 2022).

Once the oil has been extracted, the remaining wood still retains some aromatic qualities, and is generally reduced to powder (exhausted powder) for use in incense or bakhoor (scented bricks). The powder can also be pressed into small statues, often of religious significance. Lower grades of wood may also be carved into objects like sculptures and beads that retain their aromatic qualities for years, although it appears that most of the beads in circulation are of other woods soaked in agarwood oil (UNODC 2016).

Markets and prices

Agarwood is known as the most expensive wood in the world. In 2018, worldwide sales of agarwood chips alone amounted to USD 30–32 billion and are predicted to reach USD 64 billion by 2029 (Persistence Market Research 2019; Ash 2020). This represents a huge increase from the estimated market value of USD 6–8 billion suggested by Akter et al. (2013) less than a decade ago. An estimated 75% of current sales of agarwood chips are made in the Middle East and Africa, East Asia, and Southeast Asia, with top-grade agarwood selling for as much as USD 100 000/kg (Ash 2020).

Agarwood oil is also extremely valuable. In 2021, the price of the oil reached USD 487/tola (1 tola ≈ 12 ml, giving a price per litre of about USD 40 500), up from USD 325/tola in 2005 (Oud Oil Trading 2022). Market Watch (2022) stated that the global agarwood essential oil market, used in cosmetics and therapeutics, was valued at USD 131.8 million in 2019. Interestingly, small landholders and small enterprise owners, who are at the very beginning of the value chain, only earn USD 100–600 per month (see Section 6).

There is growing concern that the supply of wild-origin agarwood is becoming severely reduced. The result could be even higher prices for wild-origin product in future, and speculative buying and stockpiling (Ensar Oud 2011; UNODC 2016).

Quality of planation vs. wild agarwood

As a result of the decline in wild populations of agarwood-producing trees, exporting countries are increasingly turning to plantations as a way to maintain their export business and income. However, while plantations may have been successful in terms of cultivation, the agarwood they produce is widely considered to be of lower quality that its wild-sourced equivalent (Tamuli et al. 2005; Bhuiyan et al. 2009; Devi 2021).

Some analyses have found significant differences in the concentrations of oils and aromatic compounds between plantation and wild agarwood samples (Tamuli et al. 2005; Espinosa et al. 2014). A possible explanation may be the rapid turnover of plantation agarwood. Plantation trees are harvested as soon as two years after infection, providing limited time for aromatic compounds to accumulate, whereas wild trees may have grown for decades before they are harvested (Mustafa et al. 2022; Hoang Giang Agarwood: www.hgagarwood.com). As a result, some farmers and investors may be hesitant to invest in agarwood cultivation. However, research to improve the quality of plantation products is ongoing, and the quality of plantation agarwood has somewhat improved over time (see Section 5).

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Agarwood product glossary

In 2007 at CITES COP 14, Decision 14.10 requested the Parties to produce an identification manual, or glossary, for agarwood products. The purpose of the manual was to standardize the names used for the reporting of different product types. A preliminary document was co-written by authors from Kuwait, Indonesia, China, and Thailand and delivered to CITES at COP 16, with an updated version provided to Parties at COP 17. The glossary is available on the CITES website. However, it has not been endorsed by all Parties. PC 25 considered some proposed revisions to the glossary but recommended not to make any amendments at that time. No further versions have been developed and so the glossary has still not been fully accepted.

The current version of the glossary[14] lists 21 products, from plant parts such as leaves and seeds to medicine and a pooled category called "Finished products packaged and ready for retail trade". However, some Parties consider the number of product types excessive (Malaysia, for example, only registers nine products) and/or are concerned about the value of the glossary for enforcement. Specifically, definitions including those for wood pieces, chips, logs, and blocks have been considered unclear, while some Parties have reservations about differentiating between exhausted and non-exhausted powder. A good example is the description of chips as "small to medium pieces of agarwood" without defining the terms "small" or "medium" in terms of some minimum and maximum weight. Such issues need to be resolved to create a single globally applicable glossary and enable the use of consistent categories in the CITES database. The ongoing problems would indicate that CITES should consider convening a new working group meeting to deal with the glossary issue, with the key Parties invited. The CITES Tree Species Programme – Validation Workshop on Agarwood convened in 2022 to review this report provided some further guidance (see recommendations in Section 8).

Illegal trade and enforcement

CITES has listed all *Aquilaria* and *Gyrinops* species on Appendix II, meaning that exporting and re-exporting countries must have a CITES export permit, issued by the country CITES Management Authority, to sell any agarwood parts (except parts as covered under Annotation 14—see above) to an importing country. Importing countries are not required to provide an import certificate. They are, however, supposed to ensure that the paperwork is in order and matches the products in question, and some countries have supplied CITES voluntarily with information on agarwood imports.

Illegal harvesting represents the main threat to the remaining wild stocks of agarwood-producing species (UNODC 2016). Agarwood products comprised 6% of global seizures by value between 2005 and 2014, 4% of seizures between 2009 and 2013, but dropped to 0.6% between 2014 and 2018 (UNODC 2020). Their reports also noted that it is likely that only a very small proportion of illegal product is seized in any given year. Interestingly, agarwood is mentioned 71 times in the 2016 UNODC report, but only five times in the 2020 report, suggesting that perhaps there has either been reduced enforcement effort, or that the amount of illegal product has declined. Unfortunately, the UNODC reports did not indicate amount or types of materials seized and so there is no way of determining if a possible decline in illegal agarwood, as suggested, was an actual decline in product seized, a relative increase in other products seized, reduced enforcement efforts, or an increase in the value of some of the other products reported. The UNODC data indicated that most seizures occurred from 2007 to 2011, and there was very minimal information on agarwood seized products in the 2020 UNODC report. CITES receives illegal seizure reports annually from most countries, but those data are confidential, and so it was not possible to corroborate the UNODC information.

Figure 12. Illegally harvested *Aquilaria* tree. Photo: Kadoorie Farm and Botanical Garden, Hong Kong SAR

UNODC indicated that illegal agarwood products are largely laundered through plantation operations, with no way to follow chain of custody, and Lim et al. (2022) concurred. Since that

[14] Annex to document PC22 Doc. 17.5.3.

report (2016), some countries, such as Thailand, have required that all agarwood products be registered and made it illegal to acquire products of unknown origin, so that chain of custody can be followed. Most of the illegal agarwood product seized was shipped from Malaysia, Indonesia, and India destined to Saudi Arabia, the United Arab Emirates, Kuwait, Bahrain and Japan (UNODC 2016).

Illegal harvest of agarwood continues to take place throughout Peninsular Malaysia, Sabah and Sarawak. Researchers in Malaysia found that, between 2011 and 2015, more than 25% of the *Aquilaria* trees were lost at two monitored sites, of which 85% were illegally harvested (Chua et al. 2016). This harvesting is being carried out by local people as well as foreign nationals. Data from Peninsular Malaysia showed that 46 arrests for illegal harvesting of agarwood-producing species were recorded in 2019, but none during the following two years, although three arrests occurred in Sabah in 2021 (Lim et al. 2022).

In addition, some Malaysians have been involved in agarwood harvesting in neighbouring countries. In particular, Lim et al. (2022) reported that Malaysians have entered Brunei Darussalam from Sarawak to harvest agarwood and then smuggle it back into Malaysia for export. Since 2010, the government in Brunei Darussalam has hired local Indigenous people to assist with enforcement by conducting jungle patrols, especially to curb poachers from Malaysia.

Indonesia pools its data for arrests and seizures related to endangered species and does not publicly report data specifically for agarwood. The data shows a small but slightly increasing number of arrests (mean arrests were 58 per year) between 2015 and 2021 (Turjaman 2022).

A presentation by Myanmar at the 2022 CITES workshop indicated total legal agarwood exports of only 516 kg during the past three years, despite the country having about 300 ha of plantation. This would indicate a considerable amount of agarwood is leaving the country through unknown means. Data from Cambodia suggest a similar situation there.

Importing nations have a significant role to play in detecting and interdicting illegal agarwood trade, and in encouraging the sourcing of legal and traceable agarwood products. This is a complex problem, however and requires customs officers who are trained in the identification of agarwood products and understand the importation requirements.

Figure 13: Protective cage to stop poachers from cutting trees. Photo: Kadoorie Farm and Botanical Garden, Hong Kong SAR

Examples of illegal harvesting are regularly reported in the media, including the following recent examples (from published news reports, unless otherwise referenced):

- In Peninsular Malaysia in 2020, police raided and shut down an illegal agarwood oil operation, seizing agarwood worth USD 500 000.
- In Sri Lanka, in 2015 and 2016, 89 212 kg of agarwood chips were confiscated as poachers were trying to export it illegally to India, South Africa and the United Arab Emirates. The Sri Lankan CITES focal point noted, while the *G. walla* is listed under the recent endangered species act, nevertheless that illegal harvesting and land-clearing has rendered the population very low by 2022.

- In Hong Kong Special Administrative Region (SAR) China, there were more than 100 cases of illegal cutting reported each year for 2014 and 2015, though that rate halved in 2016–18, possibly as a result of improved enforcement (Anon. 2018). Also in China, Chen et al. (2019) reported 690 cases of illegal harvesting from 2010 to 2018.
- In the Philippines, there have been several reports of wild agarwood seizures, varying in size from 17 to 73 kg, and totalling at least 145 kg, between 2018 and 2021.
- In Mumbai India, 525 kg of illegal agarwood, sourced in Assam and destined for the Middle East, were seized over a 7-month period in 2018.
- At the 2018 CITES agarwood workshop, Myanmar reported that while it was illegal to export wild agarwood or agarwood that cannot be accounted for, much wood was being illegally exported through India, China, and Thailand. The presentation stated that CITES implementation was not a priority for the Myanmar Forestry Department.
- In Brunei Darussalam, authorities are now deploying drones to monitor illegal agarwood harvesting, after losing many trees over the past few years to illegal foreign loggers.

These examples suggest that the illegal trade in agarwood is still very much ongoing. Given the current high price of agarwood, the illegal harvesting and trade in agarwood also seems certain to continue in future.

Timber tracking and tracing: distinguishing agarwood species and country of origin

DNA-barcoding is an emerging tool to identify trees to the species level, and can contribute to monitoring the timber trade and enforcing conservation laws (Jiao et al. 2020). DNA barcoding has been used successfully in several studies to distinguish *Aquilaria* species (e.g. Lee et al. 2016; Thitikornpong 2018; Pern et al. 2020; Tanaka and Ito 2020; Lee et al. 2022). For example, Lee et al. (2016) were able to distinguish among *Aquilaria* species from wood samples, as well as among *Aquilaria, Gyrinops,* and *Gonystylus* genera. The same study also found that the method could identify the country of origin for various products. Pern et al. (2020) were able to use DNA barcoding to distinguish between *A. beccariana* from Peninsular Malaysia and trees of the same species from Borneo. While they could similarly distinguish *A. beccariana* from other species, the level of distinction needs to be improved with further research on other genetic markers. Studies have also indicated the potential for the method to ensure quality control in agarwood medicinal products.

DNA barcoding is one of several methods and technologies in use or development to identify and track timber and wood samples. Others include examining wood anatomy, barcoding, DART-TOFMS, stable isotope and DNA assessment, chain-of-custody paper documentation (sometimes with barcodes), gas chromatography, mass spectrophotometry, and infrared colouration detection. These methods can be applied at any point on a product supply chain to verify origin, but all require the establishment of databases of benchmarks against which to verify a sample. Tracking systems need to be a legislated requirement and incorporated into existing structures and management systems (Seidel et al. 2012).

Subsequent work by Lee et al. (2022) developed DNA databases of *A. malaccensis* as tracking tools at species, population, and individual levels for use in forensic investigations and for chain of custody certification. Two DNA markers and some rRNA markers enabled distinguishing among *A. malaccensis, A. hirta, A. microcarpa, A. beccariana, A. crassna, A. sinensis*, and *A. rostrata*. The study included two case studies illustrating how the DNA databases enabled the tracking of *A. malaccensis* samples back to the Malaysian origin population and even the stump of the tree from which the sample originated. The authors noted, however, that while the databases are ready for

use in enforcement, successful application will require a policy framework and depend on collaboration among enforcement agencies, governments, private enterprise, timber certification organizations, and community members to enable sustainable agarwood management. For Malaysia, the cost of analyzing samples for agarwood tracking and verification of geographic origin is about USD 440 per sample, with delivery of results in 14 working days (Lee, pers. comm.).

Distinguishing agarwood from other woods

The "InsideWood" project[15] provides a searchable database into which anatomical characteristics measured from a wood sample can be entered to identify species. *Aquilaria* and *Gyrinops* are readily distinguished from trees, including fragrant trees, of other genera, based on only a few characteristics. However, samples cannot be readily distinguished to the species level (Gasson 2011).

More than 150 compounds have been found in agarwood that give it its aromatic and medicinal properties. The main phytochemical constituents are mixtures of sesquiterpenes and 2-(2-phenylethyl)chromones (PECs). Other dominant compounds include: agarofurans, cadinanes, eudesmanes (and selinanes), valencanes, eremophilanes, guaianes, prezizanes, vetispiranes, alongside smaller components such as benzene, toluene, and naphthalene (Naef 2011; Chen et al. 2012; Subasinghe and Hettiarachchi 2015; Naziz et al. 2019).

Lancaster and Espinosa (2012) tested three species of *Aquilaria* (*A. crassna, A. sinensis and A. malaccensis*) against 25 other scented wood genera[16] using a mass spectrophotometer (specifically DART-TOFMS) to determine if the agarwoods could be distinguished. The test included samples of wood chips, sawdust, incense, and liquids. The results indicated that reliable criteria for inferring agarwood were the presence of certain diagnostic ions (specifically m/z 319.118 or 349.129) in addition to 10 or more ions characteristic of PECs. None of the other 25 woods that were tested had these characteristics. Further research is needed to confirm these findings using agarwood from different countries as well as plantation agarwood (Deep and Tajudin 2019).

DNA barcoding can also be used to identify tree species (Degen and Sebbenn 2014; Jiao et al. 2014; Lee et al. 2022). In Malaysia, the identification or authentication of *Aquilaria* to species level costs USD 300 per sample, with delivery of results in 7 working days (S.L. Lee, pers. comm.).

Distinguishing plantation from wild-origin agarwood

Among the implementation challenges for CITES controls within countries are the inability to differentiate wild from artificially propagated agarwood, and the lack of knowledge among smallholders about how to comply with agarwood trading regulations. It is of particular interest to agarwood-producing countries to be able to export products from plantations that can be sustainably managed, as opposed to wild trees that are endangered and should not therefore be used for exported products. While some countries have instituted registration systems that can identify products and follow the chain of custody, there is still a perception that wild wood, usually illegally harvested, is included in some shipments of wood from plantations (UNODC 2016).

Espinosa et al. (2014) were able to distinguish between plantation-origin and wild-origin agarwood products of *Aquilaria* genus (*A. crassna, A. beccariana,* and *A. sinensis*) using DART-TOFMS analysis of paired planted and wild samples of wood chips from four countries (Thailand, Viet Nam, Malaysia, and China). The analyses found concentrations of specific ion groups that differed between cultivated and wild samples, regardless of the country of origin. At the same time, the

[15] https://insidewood.lib.ncsu.edu/welcome

[16] Including: *Abies, Boswellia, Caesalpinia, Caryocar, Cedrela, Dalbergia, Iranthera, LIcaria, Machaerium, Phoebe, Pterocarpus, Schefflera, Scleronema, Swartzia, Swietenia, and Santalum.*

ions distinguishing wild from plantation agarwood mostly differed among countries, indicating that, in many cases, country of origin could also be determined. While the method requires specific equipment and a statistical analysis, it was successful for 85% of the cases tested. The incorrectly classified samples likely were the result of low resin content in the tested samples. As previously discussed, there is evidence that agarwood from plantations is inferior in quality to that from wild plants (e.g. Tamuli et al. 2005; Bhuiyan et al. 2009), so the fact that distinguishing between the products is possible based on an analysis of the odour-producing components should not be surprising.

Zhang et al. (2014) examined the chemical composition of agarwood oil of *A. sinensis* extracted from healthy trees, from wild agarwood, and from plantation agarwood (that was infected with the fungus *Lasiodiplodia theobromae*). They found that the composition of oil from inoculated and wild trees were similar but that sesquiterpenes found in the wild agarwood (such as spathulenol, elemol, agarospirol, corymbolone and cyclo-isolongifolene) were absent in fungal-inoculated samples. In a similar study comparing oils from wild and chemically induced *A. sinensis* agarwood, Chen et al. (2011) recorded several notable differences in the composition of sesquiterpenes and aromatics, including benzylacetone, γ-eudesmol, eudesm-7(11)-en-4α-ol, α-Copaen-11-ol, and baimuxinal. Likewise, Yang et al. (2021) was able to distinguish wild and cultivated agarwood of *A. sinensis* based on sesquiterpenes and PECs with gas chromatography-mass spectrophotometry. These studies provide a strong indication that wild and plantation origin agarwood could be separated by their chemical components. The drawback is that the tests require a laboratory with specialized equipment and trained technicians.

Wang et al. (2020) used genetic markers to test agarwood reported as wild stock (illegally harvested by poachers) against plantation stock of *A. sinensis*. They were unable to distinguish between the two sources of wood, suggesting that the illegal wood was actually stolen from plantations. The implication, however, is that the use appropriate genetic markers can distinguish wild from planted *A. sinensis*. Similarly, Shen et al. (2019)[17] were able to distinguish *A. sinensis* from different regions of China using DNA barcoding methods.

5 Review of standing agarwood-producing tree resources

A questionnaire (see Appendix) on populations and management of agarwood trees was sent to relevant authorities in the following countries and provinces to assist with the preparation of this report: India, Indonesia, Malaysia, Bangladesh, Sri Lanka, Myanmar, Thailand, Cambodia, Viet Nam, China, Singapore, the Lao People's Democratic Republic, and Papua (the latter through the Indonesian Agarwood Association). The recipients were either major range state exporters, or countries fully within the distribution of *Aquilaria* but where the CITES export data were unclear. Answers were obtained from: Indonesia, Malaysia, India, Cambodia, Thailand, the Lao People's Democratic Republic, China, Viet Nam, and Sri Lanka. Despite follow-up emails and a request directly from the CITES Secretariat for information, Bangladesh, Myanmar, and Papua did not respond. Singapore responded that it only re-exports agarwood products, although there is some *Aquilaria* in its remaining forests. CITES circulated a similar questionnaire about agarwood in 2020 and received responses from only four countries: Bhutan, China, Cambodia, and Thailand.

In the wild, *Aquilaria* and *Gyrinops* trees occur at a low density (up to 2/ha) and very few trees produce agarwood, with estimates ranging from 1% to 10% of all wild trees (Oldfield et al. 1998; Soehartono and Newton 2000; Blanchette et al. 2015). A census of illegally felled *A. crassna* trees

[17] Much (but not all) of the research on *A. sinensis* is published in non-mainstream journals (e.g., African Journal of Biotech) and is not subject to rigourous peer review.

in the north of the Lao People's Democratic Republic indicated a density of 2.2 trees/ha (Jensen and Meilby 2012), which is high considering that felled trees must have been at least 10 cm dbh, meaning that smaller stems were not included in the estimate.

For populations, some countries have reported an estimated number of trees, while others have only estimated the area of plantations (Table 2). Trees are reported in one or several categories: plantation, wild, home garden, or research plots. In some cases, it is uncertain if the numbers refer only to plantation stock, or represent a combined estimate of wild trees plus those in plantations and home gardens. For most countries, there remains high uncertainty about the status of the wild population or the plantation population (or area planted) with, for some, vastly different estimates based on the various sources of data, sometimes as reported just a few years apart (e.g. Bhutan, China, Nepal) (Table 2).

In 2017, the *A. sinensis* population in China was reported as: 70 442 trees from 20 to 30 years old in Guangdong, 59 888 trees from 2 to 30 years old in Hainan, and 2 trees of more than 40 years in Guangxi, with 300 scattered trees remaining in Hong Kong SAR (Li 2014 in Chen et al. 2019, Anon. 2018) as a result of increased protection measures (Figures 12 and 13).

However, there is some uncertainty about the plantation population in China, with a difference of 50 million trees based on the two sources of data (Table 2). The most recent figures reported for China, based on this study's questionnaire, suggested at least 30 million planted trees in Guangdong and Hainan provinces alone.

Similarly, Viet Nam responded with an estimated 20 000–30 000 ha in plantation to a CITES questionnaire in 2020, but responded with 16 000 ha for this study, while reporting 18 000 ha in 2018.

Lok and Zuhaidi (2019) reported 24 000 ha of plantation in Malaysia, a figure that differs considerably from that reported by Azren et al. (2018) (Table 2). The Malaysia CITES website stated that 1 571 000 *Aquilaria* trees had been planted in Malaysia by the State Forestry Department and private plantation companies by 2017. The last census of wild trees in Malaysia (2011–13) reported more than 1 million stems (Table 2), with a basal area of 0.627 million m^3 (Lim et al. 2022).

Indonesia has not conducted a full census of its wild agarwood tree species populations nor of the area of plantations (Turjaman 2022). Earlier data from Indonesia suggested that *A. malaccensis* is likely restricted to the islands of Sumatra (tree density estimated at about 0.4/ha) and Borneo (East and West Kalimantan, tree density about 1/ha) (Soehartono 1999; Soehartono and Newton 2000; Partomihardjo and Semiadi 2006). Soehartono and Mardiastuti (1997) considered the species to be virtually extinct in West Kalimantan and populations were noted to be depleted in areas of Sumatra including North Bengkulu, Siberut (Mentawai Islands)[18] and East Kalimantan[19]. A census of *G. versteegii* in Indonesian Borneo suggested a wild population of only 2 500 trees remaining (Sutomo et al. 2021). A survey conducted in Indonesia for planted agarwood trees was reported by Turjaman and Hidayat (2017) (Table 2, CITES meetings column). The most commonly planted species were *A. malaccensis* followed by *A. crassna, A. microcarpa*, and *G. versteegii*. Turjaman (2022) noted that the habitat for wild agarwood-producing trees is decreasing in Indonesia due to forest fires, conversion of land to oil palm plantations, coal mining, and other developments.

[18] CITES PC14 Doc 9.2.2 A2

[19] PC14 Doc 9.2.2 A2

The Lao People's Democratic Republic is in the process of conducting a national census of its *Aquilaria* plantations. While it has already reported about 6 600 ha of private plantations, there are also many home gardens, government plantations, and some large company plantations, the areas for which are currently being determined. Plantations are primarily *A. crassna, A. sinensis, and A. yunnanensis* in mixed stands. Wild populations for trees > 10 cm dbh have been determined mostly for protected areas, and totalled at least 950 trees, primarily *A. crassna* and *A. baillonii*, with a very few *A. yunnanensis.*

Recent reporting from India suggested that there are at least 10 million planted trees and another 650 000 wild trees (India presentation at the CITES meeting convened to review this report in 2022). India reported an identical number of plantation trees in 2015 and these data were used to develop quotas for agarwood harvest and possible export. Plantations in India are all *A. malaccensis* and no other species is registered for cultivation. The other wild species in India, *A. khasiana* and *A. macrophylla,* have uncertain population numbers in the wild. Indian plantations are government-owned, individually owned or company-owned and there are large numbers of uncounted trees maintained by families in home gardens throughout Assam State. Most of India's plantation are young, with Assam, for example, only allowing plantations starting in 2006.

Together, these data indicate that there are now likely more than 60 million planted trees of *Aquilaria* spp. among the range states, with more plantations being started every year. As a result, there is an expectation that much more plantation agarwood will enter the market in just a few more years.

Table 2: Agarwood tree (mostly *Aquilaria* spp.) population estimates (sources: country presentations at CITES agarwood workshops in 2015 and 2018, UNODC (2016), questionnaires for CITES (2020) and for this study, and the CITES export database).

Country	Population or ha (CITES workshops 2015, 2018)	Population or ha (UNODC 2016)	Population or ha (Azren et al. 2018)	Population or ha (questionnaires for this study*** or CITES)	Exports (total kg 2016–2020) (CITES database)
Bangladesh**	6 000 ha of plantation	6 000 ha of government plantations	> 800 000 trees	5 000 ha of government plantations and 250 000 ha private; plus 1 million seedlings provided for home gardens	1 059 191
Bhutan	15 000 trees in nurseries, 2 487 in plantations, 2 443 in home gardens, 827 in research establishments, 2 341 wild trees (total: 24 000)	About 23 000 trees in plantations	20 000 trees	8.6 ha of plantation (CITES) > 100 000 seedlings planted	0.3
Cambodia**	No data provided	No data provided	No data provided	60 trees in home gardens (CITES). > 1 million trees in plantations (80% *A. crassna*, 20% *A. malaccensis*). No estimate of wild population	200 265

Country	Population or ha (CITES workshops 2015, 2018)	Population or ha (UNODC 2016)	Population or ha (Azren et al. 2018)	Population or ha (questionnaires for this study*** or CITES)	Exports (total kg 2016–2020) (CITES database)
China	130 684 wild trees, 73.8 million trees on 24 607 ha of plantation*	About 130 000 wild trees	20 million trees on 5 300 ha planted	21 767 ha of plantation in Hainan and Guangdong alone, with > 30 million trees	176
India**	10.5 to 11.5 million plantation trees	About 10 million plantation trees	10 million plantation trees	10 million trees in plantations, plus an unknown number on company-owned plantations (99% *A. malaccensis*, < 1% *A. khasiana*). Wild population estimated at: 387 576 forest trees, plus another 277 639 trees outside of forests.	149 096
Indonesia	3.12 million plantation trees	3.5 million plantation trees	3.4 million seedlings planted	No estimate of wild population is available. 3.5 million trees in home gardens and plantations	4 460 835
Lao People's Democratic Republic				At least 950 wild trees, and 6 600 ha of plantation (partial estimate, no data for southern areas)	40 697
Malaysia	1 352 200 trees	1 million trees on plantations	1.2 million trees planted on 1 300 ha	1.11 million wild stems (last census in 2013). 1 571 100 trees on 2 500 ha of plantations (in 2014), mostly *A. malaccensis*	2 321 107
Myanmar	34 475 trees in home gardens, 680 ha of plantation Plan to plant 2 million trees	34 475 trees in home gardens, 680 ha of plantation	35 000 trees	864 ha of plantation, 2 458 ha of mixed spp. Plantation	516
Nepal	500 000 seedlings planted (by 2018), 600 mature trees		< 1 000 trees in home gardens	83 000 seedlings planted last 4 years	0
Papua, Indonesia					281 749
Thailand**				219 ha in home gardens, 1 111 ha of plantation, 1 378 ha of mixed spp. Plantation (CITES). 1825 ha mixed species, 576 ha company, individual and community; 99% *A. crassna*, < 1% *A. malaccensis*	3 257 595

Country	Population or ha (CITES workshops 2015, 2018)	Population or ha (UNODC 2016)	Population or ha (Azren et al. 2018)	Population or ha (questionnaires for this study*** or CITES)	Exports (total kg 2016–2020) (CITES database)
				No data for wild population.	
Sri Lanka				No data available	20 519
Viet Nam**	18 000 ha plantation	1 million trees in home gardens, 18 000 ha of plantations	1 million trees	20,000–30,000 ha of plantation, mostly *A. crassna*; "millions" in home gardens (CITES) 16 000 ha plantation	567 548

* Data from country presentation at 2018 CITES workshop. Figures presented at 2015 workshop were 130 000 trees and 6 700 ha of plantation.

** These countries only export agarwood products from plantations and home gardens.

*** Some figures were provided at the CITES agarwood workshop in to review this report in 2022.

6 Management practices

Conservation

Trees of the agarwood-producing species now occur in very low abundance throughout their range as a result of overharvesting and deforestation. The low percentage of trees with agarwood, and the felling of trees in search of it, result in a huge waste of this resource.

Modelling of wild populations indicates that *A. malaccensis* populations could be sustained if only infected trees of 10 cm dbh or more were harvested. However, for lower density species such as *A. macrocarpa*, harvesting trees of under 30 cm dbh on a less than 15-year rotation would continue to reduce the population (Soehartono and Newton 2001; Kanazawa 2016). However, agarwood could be harvested without killing the tree by carving out the affected areas. In the case of *A. malaccensis*, the trees are suitable for coppicing. For example, traditional harvesters, such as the Indigenous Penan of Malaysia do not fell the trees; rather they check the tree through small holes and if they find agarwood, it is removed with knives (Kanazawa 2016). A similar method has been used in Viet Nam (Akter et al. 2013).

The main conservation methods applied at the national level have been legislation against the harvesting of wild trees, enforcement of harvesting regulations (see Section 4), export regulations and quotas, listing tree species as endangered, and development of plantations to reduce the need for wild agarwood. Harvesting of wild *Aquilaria* spp. trees is now illegal in most countries, with only Indonesia and Malaysia still allowing it (with controls). The latter two countries along with India and Thailand have produced NDFs for *Aquilaria* spp. (particularly *A. malaccensis*) and these can be important tools in determining a sustainable harvesting level (see Section 2).

Some countries have developed specific protections, policies and/or management programs for agarwood (Table 3). At least four countries are also using assisted natural regeneration to re-establish wild populations: China, Malaysia, Nepal, and Indonesia (in Papua). A useful approach to fostering recovery is employed in Sumatra, where Indonesia has developed geographic information system (GIS)-based maps of suitable locations for either plantations or restoration of wild agarwood populations (Ranmawaty et al. 2019). This stratified information can be useful in analyzing recovery efforts for *Aquilaria* and *Gyrinops*, given the restricted conditions under which the some of these species will grow.

In Malaysia, a set of guidelines issued in 2005 was adopted for use by all states on the Peninsula to control the harvest, trade, and processing of *Aquilaria* spp., and there are other specific guidelines

used in Sabah and Sarawak (Lim et al. 2022). For Peninsular harvesters, a deposit of RM 10 000 (approximately USD 2 600) must be paid for each license, the license has a quota of 500 kg with a royalty charge of 10%/kg, the licensee is required to supply 3 000 *Aquilaria* seedlings per year to the State Forestry Department, only trees > 20 cm dbh can be cut and flowering or fruiting trees cannot be cut, and the licensee must report their harvest to the Forest Department. The guidelines also have specific rules by which traders and processors must operate (see Lim et al. 2022 for details). Exporters must register with the Malaysian Timber Industry Board, which is the CITES Management Authority for Malaysia. Agarwood products are subject to a production quota assigned to each exporting company. In Sarawak, all of the main agarwood-producing species, including *Aetoxylon sympetalum*, *Aquilaria beccariana*, *A. malaccensis*, and *A. microcarpa*, are listed as protected plants under Sarawak's Wild Life Protection Ordinance of 1998.[20] Under the ordinane, *A. malaccensis* is a "prohibited species" to be retained when harvesting timber inside forest reserves. Both states require a license for the harvesting and export of agarwood species. Customs authorities in Malaysia collect a 5% tax on all exported agarwood products.

In Indonesia, there are no restrictions on local communities entering the forest or any system of timber concessions to control the harvesting agarwood trees, although there is a harvest quota set for each province. In reality, however, it is not possible to enforce quotas on small collectors in scattered villages, although anyone found carrying agarwood without proper documentation risks having their belongings confiscated. The enforcement of harvesting quotas is stricter in Papua, where agarwood harvesters must obtain a license from local chiefs. Wild-harvested wood in Indonesia is nevertheless subject to a number of regulations and to a registration process, including certification as part of the export quota for wood to be exported (Figure 14). Wild agarwood exporters must be a member of the Indonesian Agarwood Association (ASGARIN) and have permits identifying them as "overseas distributors".

The Indonesian rules for exporting agarwood apply to wild wood only. While plantation-sourced agarwood has been circulating on the market, the regulations do not recognize the existence of artificial agarwood and CITES data indicate that Indonesia exports only a small amount of wood derived from plantations. Agarwood farmers in South Kalimantan have sold plantation agarwood in the form of chips at low prices to buyers who then mixed it with wild agarwood of the same quality (class AB). Traders have indicated that, if artificial agarwood is kept separate for export, the price is too low to be worth their effort (Turjaman 2022).

India does not allow the harvest of agarwood in government forests, but there are populations in community forests. The export of agarwood is prohibited in raw form (including powder, flakes, dust and charcoal), but the export of agarwood oil and live plants is permitted. The Government of India is currently developing a registration system for agarwood growers, agarwood distillers, and processors of raw to finished products. Traders and exporters can purchase agarwood products through the system, called the LPC (Legal Procurement Certificate), and subsequently trade it within the country. Exporters can also purchase agarwood through the LPC system and export it with a CITES permit and a phytosanitary certificate issued by the plant quarantine/plant protection branch of the Ministry of Agriculture.[21]

Thailand and Viet Nam have formal registration systems for plantation agarwood. Under a 2017 law, the Government of Thailand has implemented controls on CITES-listed plants, including

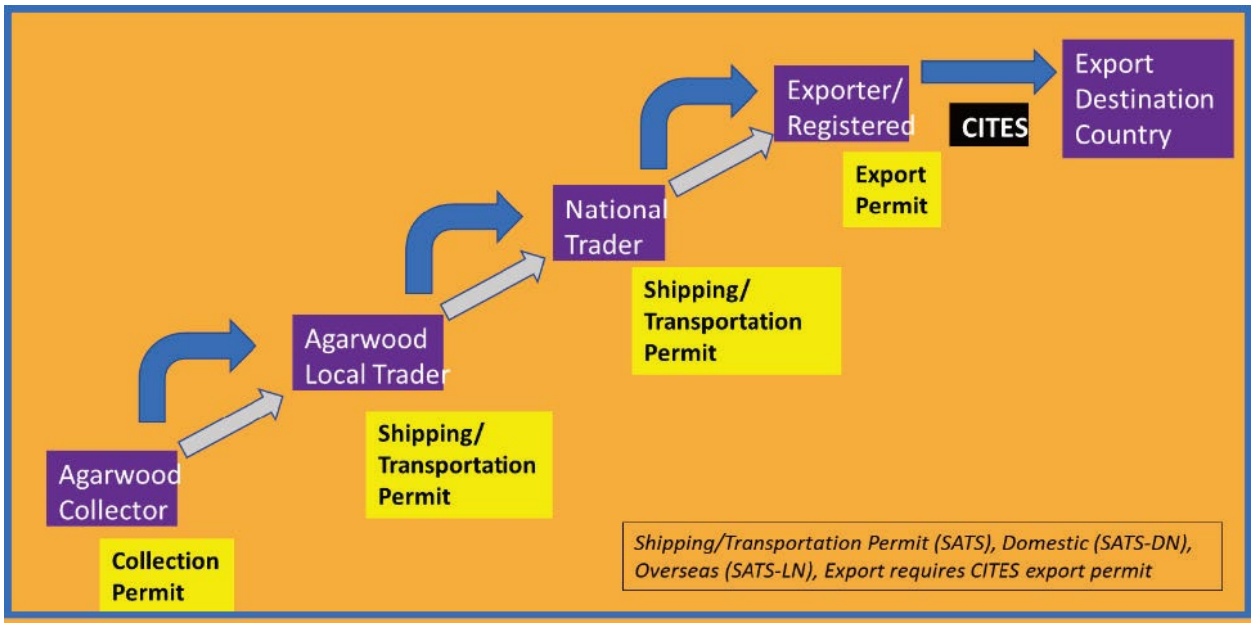
[20] https://www.sarawakforestry.com/pdf/laws/wildlife_protection_ordinance98_chap26.pdf

[21] https://moef.gov.in/wp-content/uploads/2019/06/Draft-Guidelines-for-Liberalizing-Felling-and-Transit-Regime-for-Tree-Species-Grown-on-Non-ForestPrivate-land.pdf

plantations of *A. malaccensis* and *A. crassna*, and established an online national agarwood registration system. The regulations govern cultivation under controlled conditions and the legal acquisition of parent stock from private or state lands in Thailand or purchased internationally. Growers of agarwood must register such purchases electronically with the Department of Agriculture, providing details including the nursery number, parent plant stock number and the quantity to be traded. In addition, all plantations are registered, verified by inspection, and must have management plans that ensure sustainability. Starting in 2022, plantation owners must inform authorities five days before harvesting and detail which products (woodchips, oil, etc.) will be derived from the harvest. Applications for export permits are thoroughly vetted and all shipments are inspected by customs and quarantine departments (UNCTAD 2017). Similarly, in Viet Nam, all *A. crassna* plantations operated by companies or households must be registered with the Forest Department, which is responsible for enforcing the regulations through local ranger stations. Permits for transport must be issued before wood can be moved from the plantation. In Viet Nam, only plantation-sourced *A. crassna* can be legally exported and trade in wild-harvested agarwood is not allowed. This is similar to the Philippines, where no wild harvest is permitted and a plantation industry was government-sanctioned in 2021. Harvesting of agarwood from the wild is also not permitted in Thailand except on private land, and individuals can possess only up to 1.5 kg of wild agarwood. All exported wood must be registered and accounted for along the value chain.

Agarwood plantations have become a major industry in China and have been encouraged by the government since 1999. All of the planted product is for internal use, with almost none exported. While plantation trees are barcoded, there is no regulation pertaining to the harvest, use, or transport of plantation wood within China. As in other countries, the harvesting of wild trees continues despite its illegality. China's management plan for *A. sinensis in* Hong Kong SAR focusses on enforcement and protection of the remaining trees including by using remote cameras, increasing research, restoring wild populations, raising public awareness, and developing plantations.

Figure 14: Indonesian procedures for collection, registration, and transport of wild agarwood domestically and for export (Turjaman 2022).



Plantations have become a major source of agarwood and represent a conservation and economic strategy used by most countries to replace at least some of the demand for wild wood (Table 3). Large-scale plantation cultivation of *Aquilaria* spp. has been ongoing since at least the early 1990s (e.g. Lok and Zuhaidi 1996), and it has been common since the 1970s for farmers in rural communities throughout the range of these species to have *Aquilaria* trees planted in home gardens. However, planation agarwood is widely perceived as being of lower quality than wild agarwood (Section 4). There is also a concern that, in the absence of wild stock and relying only on plantations, the genetic variability within and among species will slowly erode. Therefore, it is imperative that wild stock be conserved in sufficiently large numbers to sustain genetic diversity at the species level across the ranges of these species.

Planting *Aquilaria* trees has become common in Indonesia, and Turjaman (2022) suggested that the official figure of more than 3 million trees may underestimate the real number by a factor of 10 or more, although it is uncertain if any of these trees represent assisted regeneration or if are all in plantations and home gardens. Under a recovery programme for forests, the Government of Indonesia has been supplying 25 *Aquilaria* seeds or seedlings to individuals to plant in a home garden or community plantation. *A. microcarpa* is the species most widely planted in Sumatra, Kalimantan, and Java, while *G. versteegii* is commonly planted on the islands of Java and Bali, with *G. caudata* mostly planted on Papua (Turjaman 2022). Plantations in Indonesia must be registered with the government. However, the regulations are so onerous and complex that they seem to be restricting plantation development. A shortage of inoculant and concern about the quality of plantation agarwood are also discouraging people from entering the business. To remedy this situation, two provinces (Lamandau Regency in Central Kalimantan and Ambon City in Moluccas) have built laboratories to deliver *Fusarium solani* inoculants free of charge to communities engaged in agarwood plantations (Turjaman 2022).

Table 3: Measures to conserve agarwood-producing species taken by range states.

Country	Conservation measures	Management plan	Export quota and/or NDF	Plantation controls
Bangladesh	▪ No harvest of wild trees ▪ Agarwood ~~selling rules~~ trading regulations (2012)	No	No	▪ Wood from plantations only
Bhutan	▪ No harvest of wild trees	No	No	

Country	Conservation measures	Management plan	Export quota and/or NDF	Plantation controls
Cambodia	▪ 80% of natural forest protected and no harvest of wild trees permitted ▪ Develop plantations	No	No	▪ Plantation registration ▪ Harvests recorded
China	▪ No harvest of wild trees ▪ Assisted regeneration of wild population ▪ Gene bank ▪ Develop plantations in other countries ▪ Strict import/export rules	Yes (2018–2022 for *A. sinensis* in Hong Kong SAR, China)	No	▪ Plantation-grown trees barcoded
India	▪ No harvest of wild trees and no export of wild product	Yes, with a sustainable use policy	NDF and export quota	▪ Plantation registration (home garde

Country	Conservation measures	Management plan	Export quota and/or NDF	Plantation controls
	▪ Gene bank ▪ Restock wild populations ▪ Develop plantations ▪ Export quotas			ns exempted) ▪ Transport permit
Indonesia	▪ No harvest in protected areas ▪ Government-provided seeds/seedlings for individuals ▪ Develop plantations ▪ Wild population recovery programme	Yes	NDF and export quota	▪ Harvest certificate ▪ Transport permit ▪ Plantation registration ▪ Quotas for wild harvest by province and species
Lao People's Democratic Republic	▪ Wild trees protected ▪ Develop plantations	No	▪ In preparation	▪ Only plantation wood exported ▪ Plantation

Country	Conservation measures	Management plan	Export quota and/or NDF	Plantation controls
				registration ▪ Harvest certificate
Malaysia	▪ Regulated harvest in reserve forest ▪ No harvest in protected areas ▪ Restoration of wild populations ▪ Develop plantations	Yes, 2016 Conservation Action Plan	NDF and national export quota	▪ Harvest certificate ▪ Export certificate
Myanmar	▪ Export certificate ▪ No harvest of wild trees ▪ Develop plantations	No	No	▪ Plantation registration
Nepal	▪ Does not export agarwood ▪ No harvest of wild trees	No	No exports	No industry yet

Country	Conservation measures	Management plan	Export quota and/or NDF	Plantation controls
	▪ Seedlings provided to communities by government (c. 100 000/year)			
Papua, Indonesia	▪ Assisted regeneration in wild	No	NDF and quota	▪ Harvester registration (with local chief)
Sri Lanka	▪ Develop plantations	No	None	
Thailand	▪ No harvest in protected areas or of wild trees ▪ Distribution map ▪ Forest communities of > 10,000 people register for use as NTFP ▪ Develop plantations	No	NDF for *A. crassna*	▪ Registration system for plantation wood

Country	Conservation measures	Management plan	Export quota and/or NDF	Plantation controls
Philippines	▪ No harvest of *Aquilaria* spp. or removal of seeds or seedlings from wild populations ▪ Import permit for seeds or seedlings ▪ Develop plantations	No	None	▪ Transport permit
Viet Nam	▪ All wild trees protected ▪ Government-provided seeds for home gardens ▪ Develop plantations	No	None	▪ Plantation registration

Box 1: ***The ITTO-CITES Programme (2009-2016) and the CITES Tree Species Programme (2017-2022)***

This innovative and effective programme was developed jointly by ITTO and CITES to provide information and support for endangered tropical tree species used in international trade. The programmes have helped improve the management of many endangered tree species, including *Aquilaria* spp. Major funding has come from the European Union (through the European Commission) as well as other ITTO donors, including the United States of America, Switzerland, Germany, Norway, Netherlands, Japan, New Zealand and the private sector.

The programmes aim "to ensure that international trade in CITES-listed timber species is consistent with their sustainable management and conservation". Funded projects have focused on: management planning, inventories, developing NDF reports, and developing tools for timber species identification and tracking.

In the specific case of *Aquilaria* and *Gyrinops* species, a large number of projects were funded in Indonesia and Malaysia, resulting in NDFs, a species identification manual, genetic conservation actions, a grading manual, and improvements in silviculture and plantation effectiveness and efficiency. The programmes funded three important international workshops on agarwood species in 2015, 2018 and 2022, bringing together exporting and importing countries to exchange information on agarwood species management and conservation.

Malaysia, with project funding from ITTO and CITES (see Box 1), released its action and management plan for *A. malaccensis* in 2016, although a new national inventory of agarwood trees still needs to be completed (Chua et al. 2016). The plan states that the species is not resilient to current harvesting activities, that the downward trend in nationwide abundance observed since the late 1980s is continuing, and recognizes that trade is the most important contributor to the rapid decline of the resource. The plan used data on tree density and growth based on sampling from a forest plot going back more than 20 years (last census in 2013) and genetic information derived from 35 sampled forest areas to develop a strategy for conservation with the following key elements:

- *In situ* conservation of remaining trees with five separate populations in each of the two significant Peninsula genetic clusters, with at least 300 trees each, of which at least 65 trees are > 20 cm dbh, with buffer zones of 200 m;
- Only transfer genetic material within each of the two genetic clusters;
- Establish an *ex situ* plantation of 2 000 trees as a gene bank;
- Provide legal protection for the *in situ* sites;
- Develop an inventory and monitoring protocol and monitor periodically;
- Develop a harvest quota based on inventory at the state level;
- Promote enrichment planting;
- Work with stakeholders to improve management;
- Improve enforcement; and
- Create incentives for plantation establishment.

An early action plan for the conservation of agarwood species was developed in 2008 for the Lao People's Democratic Republic, Cambodia, and Viet Nam through Botanical Gardens Conservation International (Gratzfeld and Tan 2008). This plan was in response to declining populations in the Lao People's Democratic Republic, in particular, and included the following general components:

- Strengthen institutional cooperation by bringing together various stakeholders for planning activities;
- Conduct capacity building and training for agarwood conservation;
- Survey wild populations and develop species recovery programmes including improved silviculture techniques;
- Establish demonstration projects to conserve remaining wild populations and begin *ex situ* propagation in village nurseries and local botanic gardens, for reintroduction into the wild.

China's management plan for *A. sinensis in* Hong Kong SAR focusses on enforcement and protection of the remaining trees including by using remote cameras, increasing research, restoring wild populations, raising public awareness, and developing plantations.

India does not allow the harvest of agarwood in government forests, but there are populations in community forests. The export of agarwood is prohibited in raw form (including powder, flakes, dust and charcoal), but the export of agarwood oil and live plants is permitted.

In Viet Nam, only plantation-sourced *A. crassna* can be legally exported and trade in wild-harvested agarwood is not allowed. This is similar to the Philippines, where no wild harvest is permitted and a plantation industry was government-sanctioned in 2021. Harvesting of agarwood from the wild is also not permitted in Thailand except on private land, and individuals can possess only up to 1.5 kg of wild agarwood. All exported wood must be registered and accounted for along the value chain.

Cambodia's plantation industry began operating in the 1990s and has expanded significantly in recent years, so most trees, primarily *A. crassna*, are still young. Harvesting in the wild is illegal, and plantations must be registered with the Forest Administration (Sinly et al. 2022). The Forest Administration evaluates proposals for export permits and issues recommendations for their issue. However, it appears that some plantation companies have been exporting wood without permits (Sinly et al. 2022).

Cultivation techniques

The natural process that produces agarwood starts when insects, such as ants or stem borers, enter the trunk of a tree, either through an existing wound or by causing a new wound. The insects carry bacteria and fungal spores that infect the tree, prompting it to produce resin as part of a defense mechanism. The resin impregnates part of the heartwood of the tree to form highly aromatic agarwood. In wild *Aquilaria* or *Gyrinops* trees, this process can be long and complex, involving many physiological changes, as the tree responds to the external stimuli of wounding and/or insect and fungal attack.

Figure 15: *A. malaccensis* plantation in Assam, India. Photo: Syed Quavi

Figure 16: Mixed species plantation of *A. malaccensis* and banana plants in Pontianak, West Kalimantan, Indonesia. Photo: M. Turjaman

For many years, most cultivated agarwood was produced in home gardens on small areas of private land to supplement individual incomes. However, with the sharp decline in natural populations of agarwood species throughout their range as a result of overharvesting, agarwood production has become a large-scale industry based on closely managed plantations throughout much of South and Southeast Asia (Mustapa et al. 2022). Some plantations were developed by individual farmers or financed on farms by individuals as an investment. More extensive plantations have been established by private companies or government agencies. The majority of trees planted are *A. crassna* and *A. malaccensis* (Figure 15), while *A. sinensis* is primarily planted in southern China (Azren et al. 2018), including on Hainan. Other planted species include *A. subintegra* and *A. hirta*. Survival of plantation trees exceeds 90% if correctly managed and the climate remains favourable (Blanchette et al. 2015; Rahman et al. 2015). Many farmers use an agroforestry system that integrates food or fodder crops in areas between the *Aquilaria* trees (Figure 16). This system can include commercial agriculture species such as oil palm, rubber, various fruit trees, and some smaller crops such as cassava (Desa et al. 2021). In Indonesia, agarwood has been planted along the edges of many rubber plantations and the owners inoculate some of the trees to produce agarwood to supplement their incomes. In other cases, *Aquilaria* trees have seeded naturally and then are inoculated by the farmers. Large commercial plantations, however, tend to be monocultures of *Aquilaria*.

Plantations of *Aquilaria* spp. grow best and with lowest mortality on sloping land with somewhat sandy soils up to an altitude of 750–1 000 m and with annual rainfall of 1 800–3 500 mm (Adhikari et al. 2021; Devi 2021). The upper altitude limit appears to be variable among the various species, with *A. sinensis* growing up to an altitude of only 400 m (Anonymous 2018) and other *Aquilaria* spp. growing at up to 1700 m in Malaysia. Plantations on poorly drained and clay soil suffer high sapling mortality, although *A. malaccensis* will grow on most soil types. Ideal conditions for growth are moderate tropical temperature, high humidity, fertile soil, and moderate light intensity (Auri et al. 2021). Plantations can be established by collecting and transplanting seedlings, using cuttings, or by planting seeds. Subiakto et al. (2009) found that the germination rate for direct

seeding was 82%, as compared to 42% after seeds had been stored for eight weeks at room temperature. Seed shelf life is very short at about 15 to 40 days at 25 °C (Kharnaior and Thomas 2021). For cuttings, the latter study found that the best growing medium was an equal mixture of coconut dust and paddy husk, watered twice a week.

Most plantations use a spacing of between 2 x 2 m and and 3 x 3 m, for a density of about 1 000 to 2 500 trees/ha. Some very high-density plantations of *A. crassna* were reported by Sinly et al. (2022), with more than 3 500 stems/ha (Figure 17) in southern Cambodia, although the counts included many saplings. Some of the smaller trees in these situations are destined to be moved to new plantations or into local home gardens.

Figure 17: A high density (3 500+ stems/ha) *A. crassna* plantation in Cambodia. Photo: Say Sinly

Recent droughts in parts of Southeast Asia (e.g., Thailand, Myanmar) have resulted in high agarwood tree mortality in some plantations, indicating that, under climate change, irrigation may become a necessity for some farmers and that some areas may no longer support agarwood species. Recent studies on drought tolerance indicated that *A. malaccensis* and *A. subintegra* were much less resistant than *A. hirta* (Kenzo et al. 2019).

According to information on *A. malaccensis* seedlings provided by the Government of Malaysia,[22] seedlings of this species can be collected near parent trees when they have reached a height of 10 to 15 cm. Seedlings need to be handled carefully to ensure that the main root is not damaged. The best time to collect seeds is in the morning during the rainy season and the seedling must be transferred to a polybag soon after collection. In the nursery, the seedlings should be grown in a soil with at least one-third sand and require watering several times a day. Seedlings can be transplanted at a height of 60 to 90 cm. Seedlings should be planted in a hole 40 cm in diameter and 40 cm deep that, if left open for a few days, will improve the oxygenation of the soil for root growth. The soil should also be improved by mixing in manure or fertilizer and an application of soil insecticide. Pruning can be carried out within 3 to 6 months, with a first corrective pruning to shape the tree and give it a balanced canopy-stem ratio. Stands also need to be tended to reduce competition. Lok and Zuhaidi (2016) suggested that during the first year an organic fertilizer (with a nitrogen-potassium-phosphorus ratio of 8:8:8 plus trace elements) be applied at a rate of 100 g/sapling, and an inorganic fertilizer (with a nitrogen-potassium-phosphorus ratio of 12:12:12 plus trace elements) be applied at a rate about 100–200 g from the second to the fifth year. The frequency of application depends on the conditions and growth of the tree. Lok and Zuhaidi (2019) reported that 5-year-old *A. malaccensis,* with a planting distance of 2.5 x 2.5 m, had reached > 10 cm dbh in Malaysia, which is the recommended size for inoculation.

Inoculation of trees to produce agarwood

The natural production of agarwood may take a decade or more, if it takes place at all (Naziz et al. 2019). Therefore, techniques have been developed to induce the development of agarwood and speed its production.

Small-scale farmers typically induce the development of agarwood by using low-cost tools and methods such as screws, knives, nails and drills to repeatedly wound the tree, starting when the

[22] https://mycites.frim.gov.my/en/species/aquilaria-malaccensis/management/overview/

trees are about 6 years old and have reached 10 cm dbh. Studies in Viet Nam suggest that drilling a hole and keeping it open with a small tube can yield better results (Atkin et al. 2013; Blanchette et al. 2015). After 3 to 5 years of repeated nailing or drilling, the agarwood may be sufficiently developed for harvesting (Chowdhury et al. 2017; Rahman et al. 2015), although Akter et al. (2013) indicated that farmers usually wait 5 to 10 years before harvesting and that the best production is from trees that are at least 50 years old. These mechanical induction methods, however, usually result in inferior quality and an uncertain yield of agarwood (Cheng et al. 2019). Agarwood is formed only in the injured areas, suggesting that the amount of agarwood produced depends on the number and magnitude of injuries (Azren et al. 2019).

To further improve the production of agarwood, researchers have developed techniques that are now used on most plantations. Exceptions are plantations in the Lao People's Democratic Republic and some areas of Bangladesh, where physical wounding remains the main technique. These techniques include inoculation with various fungi (Santoso et al. 2011; Suharti et al. 2011; Liu et al. 2013; Mohamed et al. 2014) combined with aeration (Chowdhury et al. 2017), and chemical induction (e.g. Liu et al. 2013). Both techniques have been found to enhance production of cultivated agarwood that is similar to natural agarwood. However, some studies have indicated that the chemical compounds found in cultivated and natural agarwood are distinguishable (Espinosa et al. 2014; Blanchette et al. 2015; Azren et al. 2019), although information was limited especially for agarwood produced using chemical inducement. Other studies have shown that different production methods result in different amounts of the chemicals that give agarwood its aromatic properties (Naef 2011; Liu et al. 2013) and suggested that more research is required to determine the best method for the various tree species and the locations where they are planted.

Fungal inoculation

The precise fungal pathogens and their mixtures used as inoculants, along with the physical location of a tree have also been found to have a large effect on the yield and quality of agarwood (Chippa et al. 2017). Plantation agarwood is now regularly harvested only a few years after inoculation and certain inoculants have resulted in significant production of agarwood after only 2 years (Mustafa et al. 2022). In Malaysia, Lok (2010) and Lok and Zuhaidi (2018) indicated a rotation cycle of 4 to 8 years after inoculation, depending on the species, growth performance, site suitability, management techniques, and effectiveness of inducement.

Several fungus genera and species that result in agarwood production in *Aquilaria spp.* have been identified using various methods (e.g. microscopy, PCR, and ITS-rDNA), and from the various species of *Aquilaria*, including the following genera: *Cunninghamella*, *Curvularia*, *Fusarium* (at least four species), *Trichoderma*, *Paraconiothyrium*, *Botryosphaeria*, *Fomitopsis*, *Lasiodiplodia*, *Penicillium*, *Epicoccum*, *Alternaria*, *Acremonium, Colletotrichum,* and *Phaeoacremonium* (Azren et al. 2019; Naziz et al. 2019). Chhipa et al. (2017) identify 82 species of fungus that result in agarwood while cautioning than only 8% of fungi present in the trees have been studied for their roles in agarwood production, and many genera may not necessarily be responsible for the resin formation. In Malaysia, research has identified *Aspergillus* spp., *Botryodiplodia* spp., *Diplodia* spp., and *Fusarium proliferatum* as the key fungi resulting in agarwood (Mohd Parid and Lim 2003; Rozihawati et al. 2022). The types and combinations of fungi reported vary by tree species and geographic location, but consistent results for agarwood production occur with *Fusarium* spp. (Akter et al. 2013; Chhipa et al. 2017). Santoso et al. (2011) found that agarwood production in trees inoculated with Fusarium fungi varied according to the location within Indonesia where the fungi were sourced; they also found that *F. solani* was the best species to use.

Aromatic compound types and qualities may vary with the type and mixtures of fungi (Chhipa et al. 2017). Recent research from Malaysia that tested several combinations of fungi found that a combination of *Trichoderma* sp., *Lasiodiplodia* sp. and *Curvularia* sp. was the most productive inoculant for agarwood formation in *Aquilaria* spp., based on the coloration and length of the infected zone after 3- and 6-month inoculation periods (Justin et al. 2020). In China, where much of the current fungal research has been done, high quality oil production was reported within a period of just 8 to 18 months after inoculation of *A. sinensis* with *Colletotrichum gloeosporioides* and *Botrysphaeria* sp. (Tian et al. 2013; Peng et al. 2015). Recent work by Ma et al. (2021) indicated much improved agarwood from *A. sinensis* infected by using fungi retrieved from infected wild trees.

Santoso et al. (2011) and Chong et al. (2012) reported that the following field inoculation methods worked best: (i) Drill injection holes of about 3–10 mm in diameter 20–25 mm apart to prevent agarwood overlapping; (ii) The inoculant is delivered in liquid form by injection with a syringe of about 1 ml per hole, or allowed to drip in from a bottle (Figure 18); (iii) The type of fungal strain determines the agarwood that will be formed, so screening for the best fungal strains is important;[23] and (iv) The quality of the agarwood formed improves with a longer incubation time.

In Indonesia, Turjaman (2022) reported that on an agarwood-producing tree of 15 cm dbh, six bottles of infusion liquid (150 ml/bottle) may be used (Figure 18). Fungal induction results in agarwood at the site of infection, so many holes are often drilled in a tree truck to maximize production, making this a labour-intensive technique.

[23] The best inoculant to use depends on local conditions, and local research may be required to provide advice on the most effective inoculant for a given area. Alternatively, inoculants produced commercially in individual countries are available, also on the international market.

Figure 18: Inoculation of agarwood using the infusion method at the Forest Research Institute, Malaysia. Photo: Kanako Ishii.



Chen et al. (2018) used a fungus (*Rigidoporus vinctus*) applied on the surface of *A. sinensis* trees to induce agarwood and developed surface inoculation kits that are available commercially for plantation owners. Several other commercial fungal inoculation kits are available, mostly from Malaysia and Indonesia (Azren et al. 2019). For example, Mustapa et al. (2022) reported that the use of an inoculant called IGB711 in Malaysia produced good results in less than 2 years. Artificially infected trees have yielded between 5 and 30 kg of agarwood/tree after 18 months (Mustapa et al. 2022) in Malaysia, which is far more than the 0.1 to 2.13 kg/wild tree (of which 0.10–0.18 kg/tree is high-grade) reported by Blaser et al. (2021). Recent work has also assessed the potential of chemically synthesized mycotoxins as inducer agents, with successful agarwood production in *Gyrinops* in Sri Lanka (Subasinghe et al. 2019).

It is clear that considerable further research is needed to determine which inoculation methods maximize the production of high-quality agarwood. For instance, only a few of the many possible fungi and their combinations have been tested. Further, multivariate models need to be developed that consider alternative explanatory factors that may affect agarwood production, including variables such as location (including soil type and site), rainfall, age of tree, diameter of tree, mixed vs. monoculture plantation, as well as the species of *Aquilaria* or *Gyrinops*.

Chemical induction

Various chemical induction techniques using phytohormones, salts, methyl jasmonate, soybean oil, brown sugar, formic acid, hydrogen peroxide, salicylic acid, and other substances have been employed to prompt trees to produce agarwood (Van Thanh et al. 2015; Kalita 2015; Chhipa et al. 2017; Cheng et al. 2019). Chemical induction is less time-consuming than inoculation because fewer treatment sites are needed, and the inducers are delivered throughout the tree via its transpiration process. A study by Liu et al. (2013) indicated that agarwood produced via chemical induction was similar in quality to natural agarwood and that yield was substantially higher than from inoculation.

The ‘‘Whole-tree Agarwood-Inducing Technique’’ (Agar-Wit) is a commercial product for producing agarwood using chemical induction that is used in China (Zhang et al. 2012). Other such commercial kits include Ca-Kit and Agar-Bit (the latter combining chemical induction and wounding) that contain an inoculant for injection (Naziz et al. 2019). The Ca-Kit indicates that users can expect an increase of 30% over natural levels of agar production (Rahman et al. 2015), but India reported (at the 2018 CITES workshop) that they had no success with this method. Similarly, chemical inoculation in the Lao People’s Democratic Republic has not been successful. It appears that only China, some plantations in Bangladesh, and a single plantation in Cambodia are

using the chemical induction technique, with all others using various combinations of fungal inoculants.

In most countries, initial agarwood extraction is a labour-intensive task done by hand (Figure 19). Despite the high cost of final agarwood products, these workers and others, such as plantation workers and haulers, are paid a very low wages by plantation owners.

Figure 19: Labourers extracting heartwood from *Aquilaria* trees by hand in Cambodia. Photo: Say Sinly

Other techniques

There is a possibility that genomics research can identify ways to enhance or cause agarwood production by identifying which genes are responsible for resin production and how they are ”switched on” (Cheng et al. 2019; Naziz et al. 2019). If the correct genes are sequenced, then mRNA technology could be employed to cause the resin production that results in the formation of agarwood (Cheng et al. 2019). Other possibilities to enhance production include the selection and cloning of superior agarwood production trees for breeding and out-planting of seeds. Genomics and genetics research on agarwood tree species appears to be of growing interest, based on the number of recent publications on the subject (for instance, an internet search for ”gene + Aquilaria” resulted on 2380 hits), particularly among Chinese researchers working with *A. sinensis*.

It is worth noting that several biotechnology companies have produced synthetic agarwood oil. There is already commercial-level success with “bio-oud”, which is marketed at about one-tenth of the price of natural product and used in perfumes and soaps. Most reviews, however, indicate that while sufficient for use in some cosmetics the aromas differ from the natural product in depth and complexity.

Insect and diseases in plantations and phytosanitary measures

Planting most any tree species as a monoculture invites health issues for the trees from pathogens and insects (Wingfield et al. 2015), and plantations of agarwood species are no exception. Plantation managers are now finding various insects and diseases in their plantations, some of which cause tree mortality. The recent emergence of the industry means that considerable work is still required to identify and learn how to manage these challenges (Syazwan et al. 2019). The latter authors reported that 19 insect pest species, from 16 different families of 5 different orders, and 12 diseases have been recorded so far and that many others are not yet known. Most insect pests are sap suckers, borers or defoliators, while the diseases are mostly root rots.

In Indonesia, larvae of the moth *Heortia vitessoides* have been problematic defoliators in plantations (Sitepu et al. 2011). Boring insects may actually increase production of agarwood, as may be the case for *Neurozerra conferta* (Borthaker et al. 2021). In India, the fungus *Fusarium equiseti* is associated with the wilt and dieback of plantation *A. malaccensis* (Pandey et al. 2019). In China, on Hainan, there is concern for *A. sinensis* in plantations owing to infection with *Colletotrichum alienum*, a fungus that causes leaf mortality (Liu et al. 2020). The latter authors indicated that about 35% of trees on their study plantation had been infected. China, India, Malaysia, and Indonesia have reported problems with insects and diseases, while some other countries seem not yet to have encountered these issues.

Most countries have phytosanitary laws and measures with respect to the importation of seeds or other live plant materials. For example, Thailand reported that under its Quarantine Act B.E. 2507 (1964), a phytosanitary certificate is required for plant products imported into Thailand. Thailand also issues phytosanitary certificates following the requirements of the destination country for live material that is exported. In Cambodia, Sub Decree No. 15 on Phytosanitary Inspection, article 2 specifies that "All plant quarantine materials brought or transported into, or exited from or transit in the territory of the Kingdom of Cambodia shall be inspected and follow the Phytosanitary Treatment", and article 3 stipulates that the "Ministry of Agriculture, Forestry and Fisheries is responsible for implementation of plant quarantine which has Plant Quarantine Authority of Department of Agronomy and Agricultural Land Improvement (as) implementing agency". In India, The Directorate of Plant Protection, Quarantine and Storage of the Ministry of Agriculture and Farmers Welfare inspects agricultural commodities meant for export as per the requirements of importing countries under the International Plant Protection Convention and issues phytosanitary certificates.

Home gardens and smallholder livelihoods

In India, the integration of agarwood with tea plants on smallholdings can add up to 45% to the total annual income of a family (Sarkar 2019). As a result, most families with any land have some *Aquilaria* trees planted on their property and buyers come to individual homes and acquire trees that are suspected of having agarwood. Also in India, planting of agarwood trees in areas used for shifting cultivation has been suggested as a supplemental livelihood option for farmers (Giri et al. 2020), a possibility to consider elsewhere as well.

A study in Bangladesh concluded that growing and harvesting agarwood in small farms had "a great role" in increasing the income of small landholders and communities, but that farmers were constrained by lack of access to technical information, capital, and technologies (Marium et al. 2019). Nevertheless, Ali et al. (2021), who also studied small-scale agarwood farming, found that financial returns to farmers only occurred after a start-up period of 16 years, meaning that other crops are needed initially to enable agarwood production. The net present value of 1 ha of agarwood plantation (over a rotation period of 12 years) in Bangladesh was estimated to be about USD 630 000 and the net annual return from agarwood-based enterprises was estimated to be just over USD 10 000 per ha of plantation (Rahman et al. 2015). A study in Nepal suggested that a 4-ha plantation with inoculated trees would produce a net profit of about USD 490 000 per rotation (Thapa et al. 2020).

In addition to the benefits to plantation and home garden owners, many supply and support workers gain employment in the agarwood plantation industry. For example, nursery owners, tree sellers, and plantation workers in Bangladesh had monthly incomes of USD 179–535, USD 119–476 and USD 71–143, respectively (Ador et al. 2021).

7 Conclusions

The taxonomy of *Aquilaria* and *Gyrinops* species is at best confusing, with different scientific names for the same species in several cases, and an uncertain number of species in each genus. Conservation of the gene pools of these species requires clarity regarding their taxonomy, so moving forward with a conservation agenda will require a revised taxonomy for these two genera.

Agarwood products continue to be in high demand for many commercial, medical, and cultural applications. Based on CITES export data, the supply of plantation product is increasing annually at a high rate, has already supplanted wild agarwood as the main origin of product in trade, and is set to increase even more in the near future as more plantations reach maturity. This does not mean,

however, that the products are equivalent in quality; there will continue to be a huge demand for wild agarwood from discerning customers, especially in the Middle East. Based on the market prices, it is clear that traders will pay considerably more for wild than for plantation agarwood, and traders in Indonesia have even said that they have difficulty selling plantation-derived products. This alone should be sufficient impetus for countries to actively manage their wild populations sustainably.

The high demand for wild agarwood has had severe negative consequences for the two main agarwood-producing genera *Aquilaria* and *Gyrinops* in the form of vast and range-wide declines of their populations. This demand will continue to put pressure on the remaining populations in the absence of proper controls and a targetted and effective assisted regeneration programme. There is no doubt, nor has there been any doubt for decades, that all of the agarwood-producing species have been unsustainably harvested, with the consequent population declines a result of both legal and illegal cutting as well as of deforestation. Despite growing concern over these declines, there is insufficient information about several of these species for the IUCN to even accurately determine their status. For the major species—*A. malaccensis, A. crassna, A. khasiana, A. rostrata, and A. macrocarpa*—some few data do exist, and the IUCN has listed them as critically endangered or endangered, with eight other species recorded as "vulnerable" to extinction. There is also insufficient population data on all of the *Gyrinops* species for a population-based IUCN ranking, though most of these species are listed as endangered by the range states. Difficulties in distinguishing among species coupled with the declines in the major species resulted in the blanket listing under CITES Appendix II of all species in both genera, and given the uncertainty around their populations, the listing is fully warranted.

It would appear that, in most cases, governments have disregarded the abundant evidence of decline over many years in favour of an unsustainable export industry. It took leadership from a very few countries, notably India and Indonesia, to achieve the CITES listing for these tree species. It is also certain that most government initiatives regarding agarwood are still highly skewed towards use and plantations, rather than the conservation of wild populations, and are therefore not effective in promoting the long-term persistence of the species in the wild (Chen et al. 2019). This lack of concern is evident in the absence of valid NDFs for most countries (recent NDFs from India and Thailand could not be evaluated in this study), the paucity of population data (excepting Malaysia, though the latest data are more than a decade old, and some data from India), and the very low enforcement effort against illegal trading and harvesting, as indicated by the few convictions obtained. Capacity, of course, remains a major issue for developing countries, but the fact that illegal wood is still entering into Middle Eastern countries clearly indicates that insufficient effort is being made to enforce the existing controls. With the development of plantations, to their credit, some governments have established registration and chain-of-custody protocols for the export of agarwood products. These processes, however, are still being used to some extent to "launder" illegal wood (UNODC 2020; Lim et al. 2022).

Remarkably (but perhaps not surprisingly), the major importing countries have done nothing to support the conservation of wild populations in the range states, despite providing ready markets for agarwood and having made large profits based on their import/export businesses. As one example, donations to support the CITES Tree Species Programme, which funds agarwood research, have been primarily made by the European Union, which imports a comparatively tiny amount of agarwood. For the conservation of the agarwood species, and a continued supply of wild products, major importing countries and businesses need to reconsider how the demand created by their businesses has affected wild agarwood populations and step forward to provide some support for improving enforcement and conservation activities for these species. One

mechanism would be to establish a conservation tax on imported agarwood that could be dedicated to the restoration and conservation of wild *Aquilaria* and *Gyrinops* in range states. Since wild agarwood commands a much higher price than plantation wood, it would clearly seem in the self-interest of importers to assist in re-building and protecting sustainable wild populations.

Agarwood production in plantations is becoming an important business in South, Southeast, and part of eastern Asia. Cultivated agarwood also provides income for the owners of home gardens and rubber plantations, and employment for labourers in community plantations. Governments have supported the development of plantation industries throughout the range of these species and export data suggest that it is replacing wild agarwood in international markets. Nevertheless, the plantation industry has encountered several difficulties including:

- the lag time from planting seedlings to harvesting of agarwood of at least 8 to 10 years discourages some farmers;
- lower quality product as compared to wild agarwood;
- lack of capacity to distinguish plantation wood from wild agarwood leading to restrictions;
- in some cases, onerous government regulation for those seeking to establish a plantation;
- lax chain-of-custody regulation in some countries leading to uncertain product origin; and
- the lack of credible and up-to-date NDFs indicating sustainable export quotas.

There has been extensive research into how best to inoculate plantation trees, especially in China and Malaysia. The results indicate that successful agarwood production depends on an understanding of the fungi that are naturally present in agarwood in a given locality, because the distribution of fungi is variable even within countries. No one inoculation technique seems especially superior to another, although wounding trees to trigger natural processes has a low and slow rate of success. Most plantations are using drip bottles to inoculate trees with fungi, while a study from India failed to confirm the successful results of using chemical inoculants reported in China. While commercial inoculants are available, there is little to no research available as to their comparative effectiveness, and most plantation owners are using locally available commercial products, which are often in short supply. Further research is needed at the local level to ascertain the best methods for inoculation in a given locality. There is also a need to build models that assess multiple causal factors for agarwood production, including site factors, tree age, the timing of inoculation, and tree species, rather than just the inoculant itself.

Best practices for plantations vary between countries and even among plantations and, because the industry is relatively new, plantation owners and researchers are still learning. However, detailed approaches to collecting, planting, and inoculating trees s are now available and have been provided in this report. It seems that some plantation owners are harvesting agarwood very early—after only 2 years or less—following inoculation. However, there is evidence that the aromatic compounds gain complexity over time and, as a result, that the quality of the agarwood is higher if left in the tree longer. Given the time it takes for the trees to grow to the 10 cm dbh recommended size for inoculation, plantation owners may be keen to realize some return on their investments. However, this may amount to sacrificing product quality and possibly higher longer-term gains.

Barcoding of trees, registration of plantations, and registration systems for transport and export have become common and work well with sufficient checks and enforcement. Concerns over distinguishing plantation from wild agarwood can potentially be overcome with DNA-based analyses, as well as by using chromatography and spectrophotometry methods. The challenges for developing countries to conduct such analyses are cost, technical knowledge, and the availability

of equipment and staff. At the import end of the value chain, more checking as product enters a country would assist considerably in combatting the illegal harvesting of wild agarwood trees.

All species of the agarwood genera can be readily raised from seeds in nurseries and out-planted. The genera *Aquilaria* and *Gyrinops* can be restored in the wild with focused conservation programmes, community participation, and improved enforcement. As a result, the main obstacles to assisted natural regeneration and the restoration of agarwood populations are political will, capacity, and funds to implement the relevant programmes. Several countries have embarked on restoration programmes, but success will depend in large part on the enforcement of bans and restrictions on harvesting to protect wild trees.

8 Recommendations

The following recommendations are based on the current study and relevant recommendations from the 2018 agarwood meeting in Indonesia[24]. They are divided into suggestions for range states, importing countries, and for CITES for future Plants Committee discussions. Some recommendations follow those made specifically for major range states Malaysia (Lim et al. 2022) and Indonesia (Turjaman, 2022) but are applicable to all range states.

Recommendations for range states

Given the poor state of wild populations and the lack of good information on agarwood trees generally, and the very high value commanded by wild-origin agarwood, considerable and urgent work needs to be done to conserve the wild populations that remain, including:

- Develop and implement periodic sampling to establish population data for all agarwood species (in plantations and the wild), and develop proper NDFs with quotas for all individual agarwood species.
- Ensure protection of wild trees through improved regulation and enforcement, and also possibly through the expansion of protected areas.
- Establish and strengthen national/regional databases for the identification of the origin of agarwood specimens. The database could contain site-specific profiles (including DNA profiles) of agarwood-producing species from range states.
- Increase the capacity and knowledge of enforcement staff and customs officers to more effectively reduce illegal harvesting and exporting.
- Establish a national registration system for plantation and wild agarwood:
    - Develop a licensing system for traders (such as India's "legal procurement certificate"), with any illegal activities by a trader resulting in the loss of the trading license.
    - Develop and implement online technologies to support the registration and monitoring process for plantations, nurseries, and for exporters.
    - Control the acquisition of parent stock from private or state lands, or purchased internationally.
    - Verify all plantations through inspection.
    - Apply transportation permits.
    - Samples of the labels used and lists of exporters should be communicated to the CITES Secretariat by exporting states, and then provided to all Parties through a Notification.

[24] https://cites-tsp.org/wp-content/uploads/2020/02/CITES-Tree-Species-Programme-Regional-Meeting-for-Asia-and-Second-Regional-Workshop-on-the-Management-of-Wild-and-Planted-Agarwood-Taxa-25-to-29-June-2018-Yogyakarta-%E2%80%93-Indonesia-%E2%80%93-Minute.pdf

- Develop and implement conservation action plans for the agarwood species, including a component for assisted natural regeneration.
- Consider creating a national agarwood species fund that would collect fees paid by users of agarwood-producing populations. The funds should be used to strengthen the implementation of national strategies to ensure the conservation and sustainable management of agarwood species.
- Out-planting programmes for agarwood species should consider genetic diversity within species and should not move seeds, seedlings, or cuttings outside the distribution range.
- Range states might wish to consider negotiating and agreeing to implement a common grading system for agarwood products based on the aromatic compounds present, colour, or other scientifically measurable characteristics.
- Range states should consider applying to funding agencies such as the Asian Forest Cooperation Organization, ITTO, the United Nations Development Programme, and others for support to develop their agarwood management plans.
- Technologies to distinguish wild from planted agarwood exist; plans could be developed/negotiated to establish regional service laboratories to carry out such analyses.

Recommendations to importing countries

- Given the lack of funding for the conservation of agarwood species, from the major importing countries might reflect on the damage already done to wild populations and consider assisting range states to restore and recover wild populations, either directly or through international agencies working towards the conservation and sustainable management of forests.
- Importing countries need to adopt technologies to distinguish between wild and plantation agarwood and apply these technologies to samples of incoming agarwood on a regular basis. Further, importing countries need to upgrade the skills and knowledge within their customs agencies to ensure the legal importation of agarwood.

Recommendations for CITES

- CITES should consider obtaining funding to work with a botanical garden (e.g. Royal Botanical Gardens, Kew) to develop a clear taxonomy for the two genera *Aquilaria* and *Gyrinops*, then consider listing the species individually, in part based on whether they are agarwood species.
- It is clear that most countries have spent considerable time on developing plantation methods, but limited time on understanding the importance of an NDF; as a result, CITES should consider working further with range states to provide improved information and training on developing an NDF.
- Parties to CITES should consider whether additional agarwood-producing species (such as *Aetoxylon sympetalum,* an important source of agarwood in Sarawak) should be included in Appendix II to make international trade regulations more comprehensive.
- Parties to CITES should consider whether existing regulations and export quotas adequately safeguard rare and endemic agarwood species such as *Aquilaria rostrata*.
- The current CITES ”glossary of agarwood products” requires further work to reduce its scope and ensure that there is clarity of the terms.
    - All products should be reported in kilograms, except live specimens reported in numbers.

- ”Wood block” and ”piece” should be a single category.
- The Plants Committee should discuss further with all range states whether the exemption of exhausted agarwood powder from CITES controls should be maintained.
- Inconsistencies in the agarwood import/export database should be addressed by working with countries to develop consistent terms for products (in line with the glossary) and to specify that products must be reported in certain units of measurement. Further consideration might be given to developing an online portal for direct information input that will only accept certain terms and units.
- Consider providing guidance on: a) the appropriateness of establishing quotas based on weight or volume; b) the extent to which such quotas relate to the number of mature standing trees, using a precautionary approach; and c) focusing on the harvesting regime rather than using standard conversion factors

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Appendix: Questionnaire used to gather information in selected range states

ITTO-CITES Agarwood Study – survey questionnaire for producing countries and experts

February, 2022

Name: _____

Affiliation: _____

1.0 Populations:

<table>
<tr><td>1.1
Wild</td><td colspan="4">Are census data available for your country on natural agarwood populations?
Yes _____ No _____
If so, please indicate total population (in ha or number of estimated trees): _____</td></tr>
<tr><td rowspan="6">1.2
Planted</td><td colspan="4">If available, please specify the area of agarwood plantations (ha) for the following:</td></tr>
<tr><td></td><td>Gardens</td><td>Mono-species</td><td>Mixed-species</td></tr>
<tr><td>State owned</td><td></td><td></td><td></td></tr>
<tr><td>Community owned</td><td></td><td></td><td></td></tr>
<tr><td>Individual/family owned</td><td></td><td></td><td></td></tr>
<tr><td>Company owned</td><td></td><td></td><td></td></tr>
<tr><td>Other</td><td></td><td></td><td></td></tr>
<tr><td>1.3
NDFs</td><td colspan="4">Do you have an existing NDF for any agarwood species? _____
If so, which species? (Please attach the NDF if it is a public document) _____
If so, what year was the NDF produced? _____ Has it ever been updated (year)? _____</td></tr>
</table>

2.0 Species

2.1 Please indicate the approximate relative abundance of the main agarwood producing species in wild populations in your country please report as species % of all agarwood trees:

1.
2.
3.
4.
5.

2.2 Please indicate the approximate relative abundance of the main agarwood producing species in planted populations in your country, please report as species % of all agarwood trees:

1.
2.
3.
4.
5.

3.0 Distinguishing plantation agarwood from wild agarwood products.

3.1 Does your country have ongoing research attempting to enable distinctions between natural vs. plantation derived agarwood? _____

- If so, has there been success? _____
- Please explain any techniques that can distinguish natural vs. planted agarwood products:

4.0 Production techniques

4.1 Please list the most commonly used techniques used to produce agarwood in your country:
1.
2.
3.
4.

4.2 Please indicate the main fungi species used in your country by tree and fungus species, if possible:

Infection technique	Tree species	Fungus species used

5.0 Population management

5.1 Please describe the main management techniques to ensure that wild populations persist in your country:

5.2 Please indicate the main practices for plantation establishment and management in your country:

5.3 Does your country require any phytosanitary measures for plantation product export? Please explain:

6.0 Products

6.1 Please list by approximate amounts, the relative amounts of products produced by your country

1. (e.g., sawn wood 20% of harvested volume, xx kg)
2.
3.
4.
5.
6.
7.

6.2 Registration: Does your country apply a registration system for exporters of pure or mixed agarwood products?

If yes, please specify the registration system and since when it was applied?