Journal of Tropical Biodiversity and Biotechnology
Volume 06, Issue 01 (2021): jtbb59221
DOI: 10.22146/jtbb.59221

Short Communication

Biomass Estimation of Eaglewood (*Aquilaria filaria* (Oken) Merr.) in the Karst Ecosystem of West Papua

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Submitted: 31 August 2020; **Accepted:** 20 November 2020; **Published online:** 18 January 2021

ABSTRACT
Eaglewood is Indonesia's important trade commodity in the form of resins from several infected species of *Thymelaeaceae*. The basis to determine its international trade quota through CITES is derived from the estimated eaglewood-producing species grown in their habitat. This paper aims to estimate the biomass of eaglewood, *Aquilaria filaria*, in the karst ecosystem of West Papua. We conducted a plot-based method and calculated the biomass of *A. filaria* using a diameter-based allometric equation and simulated using a bootstrap procedure. The results showed that 15,500 tons of naturally infected eaglewood are estimated in the karst ecosystem of West Papua.

Keywords: Agarwood, allometry, bootstrap, CITES, gaharu

INTRODUCTION

One of Indonesia's forest-based important trade commodities exported to the Middle East is eaglewood. Eaglewood or agarwood or *gaharu* is a trading name of a solid resin produced mainly from the genera of *Aquilaria*, *Gyrinops*, and *Gonystilus* which belong to the *Thymelaeacea* (Hou 1960). The resins are naturally produced in the forest due to the infection of the wood by the fungus (Budi et al. 2010; Agustini et al. 2006) and produce highly valuable fragrant used for incense, perfume industry, as well as traditional medicines (Mohamed 2016). However, due to the increasing demand for eaglewood and the shrinking of its population in the forest, the international trade of eaglewood is regulated through the Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2017). Therefore, the quota of naturally infected eaglewood producing trees in Indonesia is decided yearly by the management authority (the Ministry of Environment and Forestry) based on the consideration of the scientific authority (the Indonesian Institute of Sciences, LIPI).

LIPI, through the Secretariat of Scientific Authority for Biodiversity, provides the scientific-based evidence to decide the quota of eaglewood yearly based on the latest population study of the species. A recently published population study of the eaglewood producing tree by Destri et al. (2020) showed that the density of the tree and seedling of *Aquilaria filaria* was around 2.5 and 2.9 ha^{-1}, respectively. This density estimation was significantly lower compared to what the previous study suggests more than two decades ago that reached 4.33 trees ha^{-1} in Papua (Soehartono 1997 in Donovan et al. 2004). Here, we provide biomass estimation of *A. filaria* as well as the biomass estimation of naturally infected *A. filaria* that grows in the karst ecosystem of West Papua (Destri et al. 2019; Destri et al. 2020; Soehartono et al. 2000). The biomass estimation, rather than its tree density (as estimated by Destri et al. 2020), is relatively applicable to decide the quota of eaglewood produced from *A. filaria*.

To estimate the eaglewood biomass in the karst ecosystem, we used data from the population study of *A. filaria* done in the karst forest of Natural Tourism Park of Beriat, South Sorong (West Papua) on 8-26 April 2019 (Destri et al. 2020). Our data was from 28 sampling units of 10 m x 10 m using purposive random sampling. Biomass estimation (AGB_{est}, in kg) was calculated using a generic allometry equation (Chave et al. 2014) based on the diameter of breast height (D, in cm) and tree height (H_{est}, in m) (Equation 1). As we did not measure tree height directly in the field, tree height was estimated using the D-based equation for the S.E. Asia region (Feldpausch et al. 2012) (Equation 2). We used the value of 0.347 (the average value of *Aquilaria*) as the specific wood density value (ρ) of *A. filaria* (Zanne et al. 2009; Chave et al. 2009), which is commonly used if the specific wood density of a species is unknown (Slik 2006). The two formulas used to estimate biomass are as follow:

$$AGB_{est} = 0.0673\ x\ (\rho D^2 H)^{0.976} \quad \text{(Equation 1)}$$

$$H_{est} = 57.122\ x\ (1 - \exp(1 - 0.0332\ x\ D^{0.8468})) \quad \text{(Equation 2)}$$

To estimate total biomass and infected biomass per area, a bootstrap procedure with 1000 replications was done with a 95% confidence interval (Canty et al. 2019; DiCiccio et al. 1996). Extrapolation of biomass from the bootstrap method was then carried out to the whole estimated karst forest area in three regencies in West Papua (Sorong, South Sorong, and Teluk Bintuni). The area of karst was calculated based on physiographic maps of Papua bird's head region (Bartstra 1998) using ImageJ software (Schneider et al. 2012; Abràmoff et al. 2004). Further, the estimation of naturally infected *A. filaria* was calculated using the assumption of Gibson (1977) that stated only 10 % of *Aquilaria* in the forest is potentially naturally infected by the fungus and produces eaglewood.

Our simulation showed that the total biomass of *A. filaria* in the karst ecosystem of West Papua is estimated stable at *ca.* 221 kg ha^{-1} (Figure 1A). Further, the naturally infected *A. filaria* is estimated *ca.* 22 kg ha^{-1} (Figure 1B). Extrapolated to the karst area, the naturally infected biomass of *A. filaria* in West Papua is predicted at *ca.* 15,511 tons (Table 1). The highest potency within the Province of West Papua is predicted found in South Sorong Regency (9,193 tons), followed by Teluk Bintuni Regency (4,932 tons) and Sorong Regency (1,386 tons).

The biomass estimation shown in Figure 1 and Table 1 has some uncertainties. The uncertainties lie in the calculation and estimation of the karst area and the inaccuracy or uncertainties of protected areas within the karst areas. The uncertainties of the karst area in West Papua is relatively high. Up to date, the distribution of the karst ecosystem in West Papua is still lacking. We use the extrapolation method to estimate the area of karst in West Papua based on the physiographic maps of Bartstra (1998), therefore, causing the over/under-estimation of the karst area. Further, within the karst ecosystem, there are some protected areas where the extraction of eaglewood is prohibited. Ideally, the biomass of infected *A. filaria* calculation (as shown in Table 1) should exclude the area of the protected forests. The combination of those uncertainties results in the uncertainties of extractable biomass estimation of *A. filaria* in West Papua.

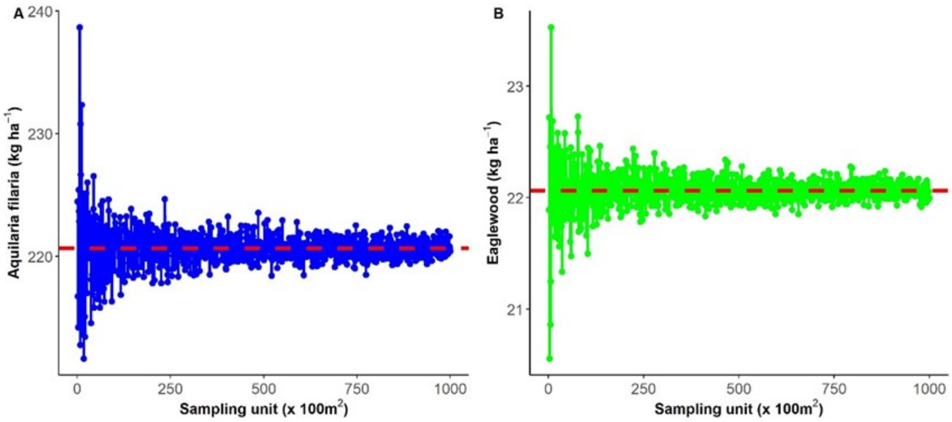

Figure 1. Biomass estimation simulation of *Aquilaria filaria* (panel A) and naturally infected *A. filaria* (panel B) in the karst ecosystem of West Papua along with the number of the sampling unit from the bootstrap procedure with a 95% confidence interval. The red dashed lines show the average biomass estimation of *A. filaria* and naturally infected of *A. filaria* (eaglewood).

Table 1. Estimation of karst area (ha), the biomass of *Aquilaria filaria* (ton), and biomass of naturally infected eaglewood from *A. filaria* in West Papua.

Regency	Area of karst forest (ha)	Biomass of *Aquilaria filaria* (ton)	Biomass of eaglewood (ton)
Sorong	62,718	13,861	1,386
South Sorong	415,991	91,933	9,193
Teluk Bintuni	223,147	49,316	4,932
Total	701,856	155,110	15,111

In conclusion, the maximum potency of naturally infected *A. filaria* in the karst ecosystem of West Papua is estimated at *ca.* 15,511 tons. This potency is still very high compared to the international trade quota of 2020 from CITES which only 490 tons. This present quota is equivalent to only 3.2% of the maximum potency in West Papua. However, even though the potency of eaglewood is still abundant, the sustainability concept must still be considered (Soehartono et al. 2002; Zhang et al. 2008; Soehartono et al. 2000). Therefore, the quota concept from CITES as well as the harvesting of eaglewood from its natural habitat must be tightened to conserve *A. filaria* in the future.

AUTHOR CONTRIBUTIONS

AHR, ZM, and DE have equal contribution to this work as the main contributor. AHR, ZM, and DE designed the project. AHR and ZM collected the data. AHR performed the analyses. AHR, ZM, and DE wrote, revised, and approved the manuscript.

ACKNOWLEDGMENTS

We would like to thank the Research Center for Biology (LIPI) for funding this research. We would also thank Balai Besar Konservasi Sumber Daya Alam of West Papua for the research permit. We are also grateful to Eko Susanto, Daseng Ahmad Samsudin, Rustandi B, Mohamad Rizki Riadhi, Abdul Rahman Wahid, Obaja Karsaw, Orgenes Karsaw, and Decky Karsaw for the help during the fieldwork.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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