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Stand structure and biomass estimation for cultivation of Agarwood-producing species on Buru Island, Maluku Province, Indonesia

Bayu Arief Pratama[a], Tika Dewi Atikah[a], Ruliyana Susanti[a], Supardi Jakalalana[a], Stanly P. Ferdinandus[b] and Rohny Setiawan Maail[c]

[a] Research Center for Ecology and Ethnobiology, National Research and Innovation Agency (BRIN), Bogor 16911, Indonesia
[b] Regional Conservation Office of Maluku, Ministry of Environment and Forestry, Ambon 97126, Indonesia
[c] Department of Forestry, Faculty of Agriculture University of Pattimura, Ambon 97233, Indonesia

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Corresponding Author:
Bayu Arief Pratama
Research Center for Ecology and Ethnobiology
National Research and Innovation Agency, Indonesia
E-mail: bayu011@brin.go.id

Abstract

Agarwood is a resin product of agarwood-producing species belonging to the Thymelaeaceae family. This product is categorized as a non-timber forest product and has high value. Species of *Aquilaria filaria* (Oken) Merr. and *Aquilaria cumingiana* (Decne.) Ridl. are two agarwood-producing species known to grow natively in the Maluku region. This research aims to observe the stand structure and biomass estimation in several *Aquilaria* sp. cultivation gardens on Buru Island. Five observation plots with sizes 20 x 20 m have been created in three villages on Buru Island. Standard vegetation analysis, principal component analysis, and simulation of aboveground biomass using bootstrap techniques have already been done. *Aquilaria* sp. is the most important species in the observed community based on the important value index and cos2 value from principal component analysis. The diversity index shows the medium category with mostly stable conditions based on the evenness index. While the biomass estimation shows an average value of 600.50 kg ha^{-1} with a standard error 273.26 kg ha^{-1}.

Keywords: agarwood, Buru Island, cultivation

1. Introduction

Agarwood is a resin product of agarwood-producing species belonging to the Thymelaeaceae family. This product is categorized as a non-timber forest product and has high value. These agarwood-producing species grew and spread from India to Malaysia and New Guinea. The Aquilaria genus is found in western and eastern Indonesia, including the Buru Islands in Maluku [1,2].

Buru Island is a small island near Ambon, the capital city of the Maluku Province. The land area of Buru Island is approximately 12,655.58 km^2. This small island is approximately 8 hours of sea travel by ship to the southwest of Ambon. Based on BPS data from 2021, this island is occupied by 213,715 people [3,4]. A total of 28.75% worked as employees, while the rest mostly worked as own-account workers or employers assisted by temporary workers. In this area, 4.53% are estate crops [3,4]. Since most of this island is already occupied by local people, cultivating agarwood-producing species is a promising effort to conserve them in their natural habitat.

Species of *Aquilaria filaria* (Oken) Merr. and *Aquilaria cumingiana* (Decne.) Ridl. are two agarwood-producing species that are known to grow natively in the Maluku region based on distribution data from Plants of the World Online [5]. Both are vulnerable based on IUCN Redlist status and are included in CITES Appendix II [6–8]. Indonesia, one of the countries in the Malesia region, exports agarwood to several countries, such as Saudi Arabia and China [9]. Generally, exports of *A. filaria* by Indonesia tended to decline from 2012 to 2021. This decline occurs in almost all forms of products, particularly chips and powders [9].

The traded agarwood is naturally harvested agarwood, the source code W. However, with increased cultivation activities and the development of gardens for agarwood-producing species, the future trade-in cultivated harvest (source code A and/or Y) can also replace natural harvest. This research aims to observed the stand structure in several *Aquilaria* sp.

cultivation gardens on Buru Island. In addition, the potential for aboveground biomass was observed to determine the biomass stored in managing the cultivation of agarwood-producing species.

2. Materials and Methods

2.1. Research Location and Time

This research was conducted on Buru Island from 2–9 October 2022. Buru Island is an island in the administrative area of Maluku Province. The island area is approximately 12,655.58 km² [3,4]. Buru Island is divided into two regencies: Buru Regency and South Buru Regency. Buru Island is 167.3 km from the provincial capital and can be reached by speedboat or ferry for 8–12 hours from Ambon to Namlea (Buru Island) [10].

2.2. Data Collection

A total of five observation plots measuring 20 × 20 m were created in three villages on Buru Island (Figure 1). Everyone with a diameter at breast height (DBH) larger than or equal to 4.77 cm was measured in diameter and tree height. Unknown species were used as voucher specimens for identification purposes.

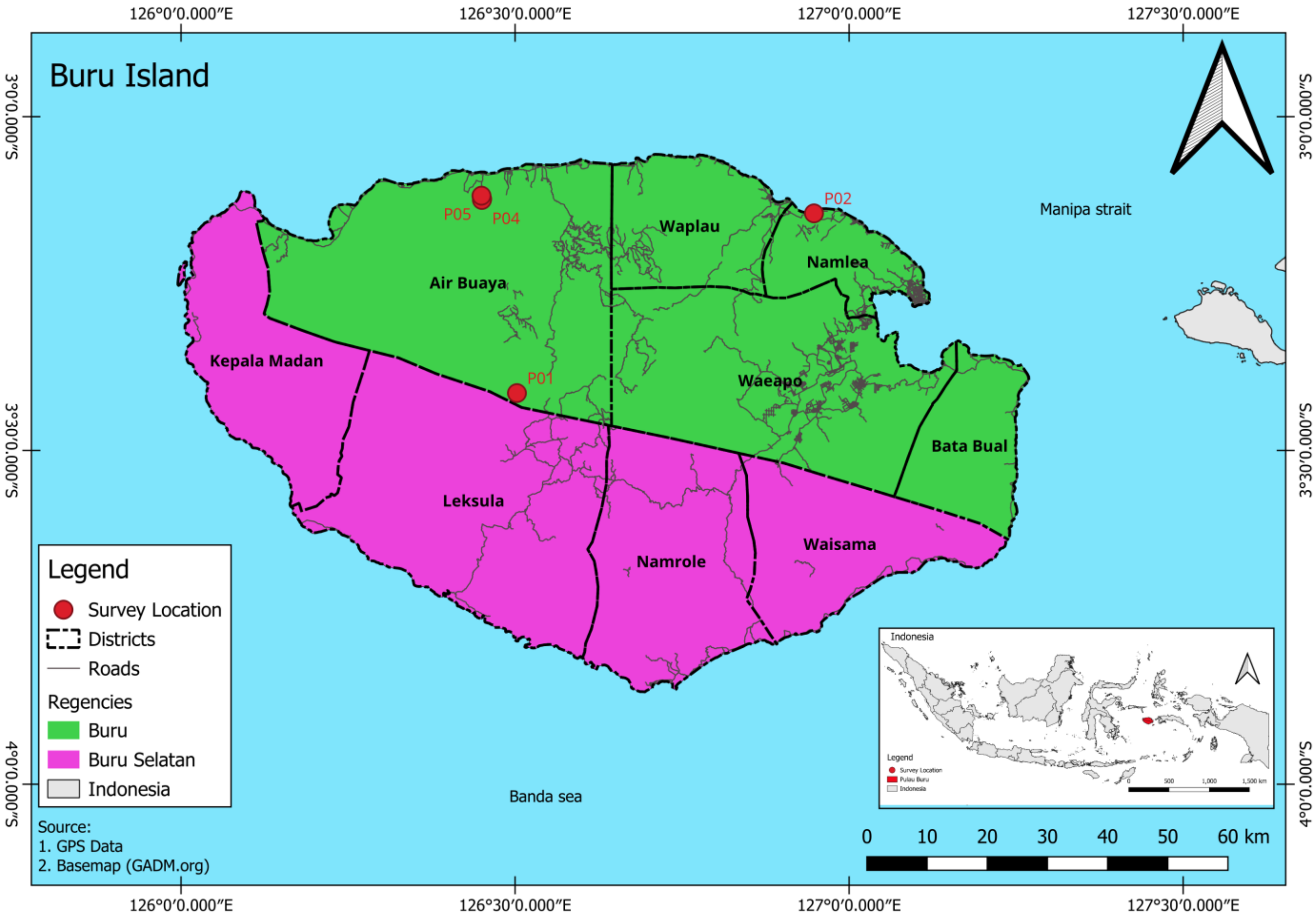

Figure 1. Map of the study location on Buru Island, Maluku, Indonesia; the dots indicate surveyed locations.

2.3. Data Analysis

Data were collected from the field and divided into seven diameter classes to identify stand structure. The diameter class was arranged using the standard statistics of the frequency distribution. The classes are 5–9 cm, 10–14 cm, 15–19 cm, 20–24 cm, 25–29 cm, 30–34 cm, and ≥ 35 cm. Diversity indices were calculated using "Vegan" packages [11] and categorized based on Magurran [12]. The categories were low diversity (H' < 1.0), medium diversity (1.0

≤ H' < 3.0), and high diversity (H' ≥ 3.0). A principal component analysis (PCA) was done to calculate important species from field data using "FactoMineR" packages version 2.9 [13] in R version 4.3.2 [14]. Standard vegetation analysis [15] and the formulas are shown in Equations 2 to 8 to compare the important species from the PCA results. The basal area was calculated using Equation 1.

Basal area (m^2)
$$BA = \frac{1}{4} \times \pi \times Dbh^2 \quad (1)$$

Density (individual ha^{-1})
$$K = \frac{Total\ individual\ of\ species}{Total\ area\ of\ all\ plots} \quad (2)$$

Frequency
$$F = \frac{Total\ number\ of\ plots\ where\ species\ found}{Total\ number\ of\ all\ plots} \quad (3)$$

Dominance ($m^2\ ha^{-1}$)
$$D = \frac{Total\ basal\ area\ of\ species}{Total\ area\ of\ all\ plots} \quad (4)$$

Relative Density (%)
$$KR = \frac{Species\ density}{All\ species\ density} \times 100\% \quad (5)$$

Relative Frequency (%)
$$FR = \frac{Species\ frequency}{All\ species\ frequency} \times 100\% \quad (6)$$

Relative Dominance (%)
$$DR = \frac{Species\ Dominance}{All\ species\ dominance} \times 100\% \quad (7)$$

Importan value index (IVI)
$$IVI = KR + FR + DR \quad (8)$$

The aboveground biomass was calculated using the formula described by Chave et al. [16]. The above-ground biomass calculation results were then simulated using the bootstrap technique to determine a stable average value for the above-ground biomass estimation results. The analysis was done also using R version 4.3.2 with "boot" package version 1.3-28.1 [17,18]. All graphs were produced using "ggplot2" package version 3.4.4 [19].

3. Results

3.1. Stand Structures

Most of the agarwood-producing species found did not flower or fruit. This creates difficulties in identifying the species; therefore, in this study, the agarwood-producing species will be written as *Aquilaria* sp. Field observations showed an inverse J-curve stand structure pattern. Most individuals were in the 10–14 cm diameter class (29 individuals), whereas the class with the lowest number of individuals was the 25–29 cm diameter class (3 individuals) (Figure 2). Meanwhile, for Agarwood species (*Aquilaria* sp.), the most numerous species were in the 10–14 cm diameter class (24 individuals), and the lowest was in the 20–24 cm diameter class (3 individuals) (Figure 2). The number of *Aquilaria* sp. individuals was 63.16% of the total species observed in this study, because the agarwood-producing species were mostly planted or grown in mixed-species plantations.

Analysis of the importance value index showed that *Aquilaria* sp. was the most important species in the observed community. However, based on the basal area, *Aquilaria* ranks third after *Cocos nucifera* and *Alstonia scholaris*. This value shows the number of individuals of *Aquilaria* sp. in the small diameter class. Table 1 shows the results. Diversity index analysis showed that plots P1 and P2 had a medium category of species diversity, whereas P3 and P4 were in the low category. P5 was planted with *Aquilaria* sp. only. Pielou's Evenness Index scores showed that the standing community in plots P1 to P3 was stable. Meanwhile, P4 was in a depressed state. P1 had the highest species richness. Simpson's Dominance Index showed a high level of dominance in plots P5 and P4. Table 2 shows the results of these analyses.

Table 1. Species found in all observation plots

No.	Species	Basal Area (m^2)	Number of Individuals	Dominance (m^2 ha^{-1})	Important Value Index
1	*Aquilaria* sp.	0.59	48	2.97	**118.98**
2	*Cocos nucifera* L.	1.14	15	5.70	82.98
3	*Alstonia scholaris* (L.) R.Br.	0.72	1	3.58	35.14
4	*Theobroma cacao* L.	0.06	5	0.31	15.61
5	*Tectona grandis* L.f.	0.05	3	0.26	12.60
6	*Nephelium* sp.	0.03	1	0.17	9.26
7	*Mangifera indica* L.	0.02	1	0.08	8.57
8	*Citrus maxima* (Burm.) Merr.	0.01	1	0.07	8.51
9	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	0.01	1	0.05	8.35

* Value in bold font is the highest

Table 2. Diversity, Evenness, Richness, and Dominance Indices

Observation plots	Diversity Index			Pielou's Evenness Index	Margalef's Richness Index	Simpson's Dominance Index
	Shannon - Weaver	Simpson	Inverse Simpson			
P1	**1.43**	**0.73**	**3.77**	0.89	**0.92**	0.26
P2	1.22	0.68	3.12	0.88	0.69	0.32
P3	0.67	0.47	1.90	**0.96**	0.23	0.53
P4	0.43	0.20	1.25	0.39	0.46	0.80
P5	0.00	0.00	1.00	NA	0.00	**1.00**

* Value in bold font is the highest

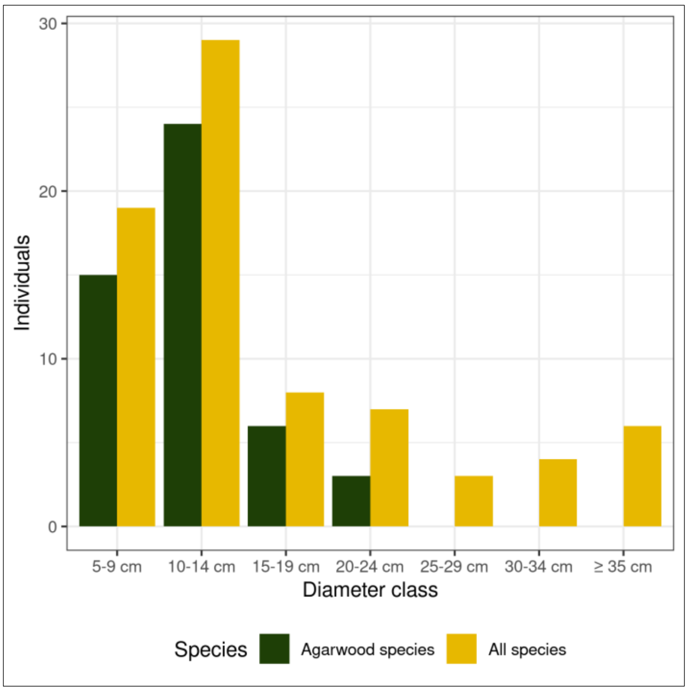

Figure 2. Diameter classes of all species compared to *Aquilaria* sp. based on field data.

3.2. Principal Component Analysis

The PCA results show that Dimension1 can describe 71.7% of the variance (Table 3). The cos2 value represented the importance of principal component. The higher the cos2 value, the better is the representation with principal components [20]. Thus, cos2 can be used to determine the importance of an individual in a community.

Table 3. Eigenvalues from Principals Component Analysis

	Dimension1	Dimension2	Dimension3	Dimension4	Dimension5
Variance	3.58	0.92	0.46	0.03	0.00
% of var.	71.70	18.33	9.24	0.68	0.04
Cumulative % of var.	71.70	90.03	99.28	99.96	100.00

Principal component analysis showed that *Aquilaria* sp. is the most important species in the observed community (Dimension 1; 0.96). It is in a group that is separate from other species. *Aquilaria* sp. and *Theobroma cacao* were in opposite quadrants, indicating that these two species did not show mutualistic symbiosis (Figure 3). *Theobroma cacao* (Dimension 2; 0.59) and *Cocos nucifera* (Dimension 3; 0.53) were the other important species. The complete results are presented in Table 4.

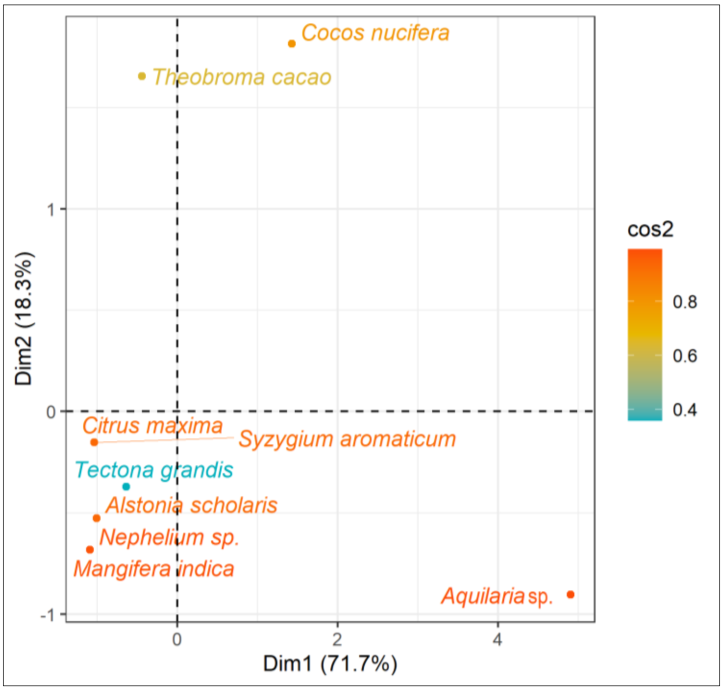

Figure 3. Contribution of individual species to each principal component. The Cos2 value shows the importance of a principal component.

Table 4. Cos2 value from Principals Component Analysis

Species	Dimension 1	Dimension 2	Dimension 3
Alstonia scholaris (L.) R.Br.	0.73	0.20	0.06
Aquilaria sp.	**0.96**	0.03	0.01
Citrus maxima (Burm.) Merr.	0.91	0.02	0.06
Cocos nucifera L.	0.31	0.49	0.20
Mangifera indica L.	0.71	0.28	0.00
Nephelium sp.	0.71	0.28	0.00
Syzygium aromaticum (L.) Merr. & L.M.Perry	0.91	0.02	0.06
Tectona grandis L.f.	0.27	0.09	**0.53**
Theobroma cacao L.	0.04	**0.59**	0.36

* Value in bold font is the highest. The Cos2 value shows the importance of a principal component.

In the variable graph, it appears that P3, P4, and P5 contribute positively to Dimension 1 (Figure 4). In Figure 5, plots P4 and P5 show a positive correlation with *Aquilaria* sp. Meanwhile, P1 had an excellent correlation with *Cocos nucifera*. This figure also emphasizes the possible clusters formed based on the species composition and observation plots.

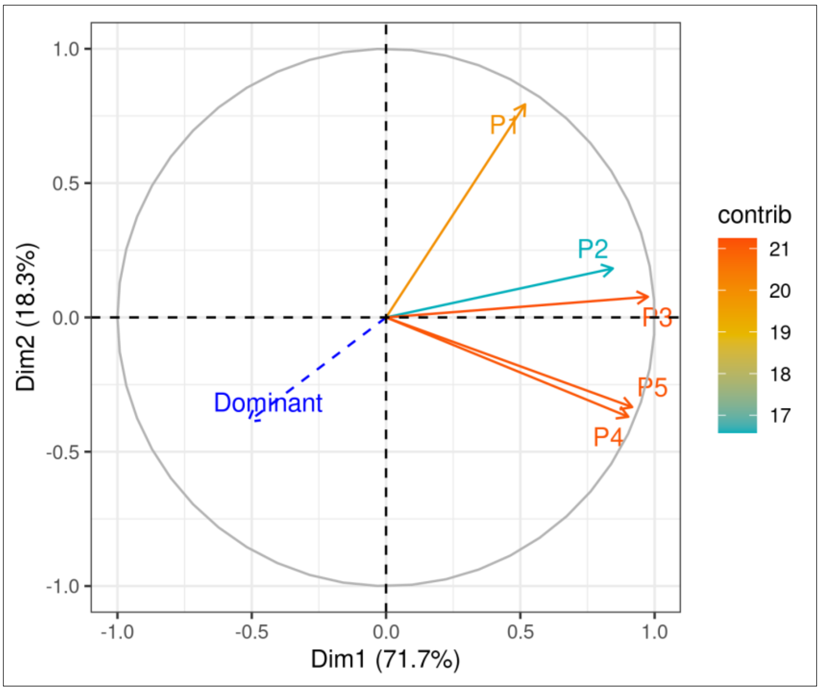

Figure 4. Contribution of each variable to the principal components.

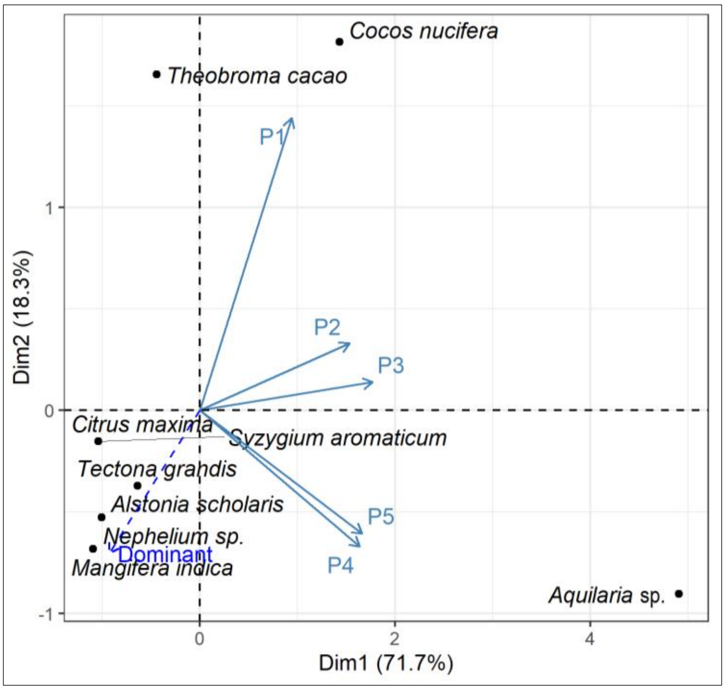

Figure 5. Biplot of Dimension 1 and Dimension 2 between species and observation plot.

3.3. Biomass Estimation

Only *Aquilaria* sp. species were calculated for aboveground biomass. P5 contained the largest aboveground biomass (996.36 kg ha^{-1}) because this plot was only planted with *Aquilaria* sp. P3 had the lowest aboveground biomass (544.34 kg ha^{-1}). Based on the number of individuals, P3 was the second plot with the largest number of *Aquilaria* sp. (8 individuals). Species of *Aquilaria* sp. in plot P3 consist of small trees with diameters ranging from 8.90 cm to 17.50 cm. The results of the above-ground biomass calculations are listed in Table 5.

Table 5. The aboveground biomass of *Aquilaria* sp.

Observation plots	Aboveground biomass (kg ha^{-1})
P1	854.39
P2	958.51
P3	544.34
P4	886.93
P5	996.36

Based on the calculations in Table 5. Bootstraps were done for 1,000 units of sampling. The bootstrap mean was 600.50 kg ha^{-1} with a standard error of 273.26 kg ha^{-1}. This value was lower than the mean aboveground biomass from the five original plots (848.10 kg ha^{-1}). The bootstrap results are shown in Figure 6. The dashed lines represent the mean values.

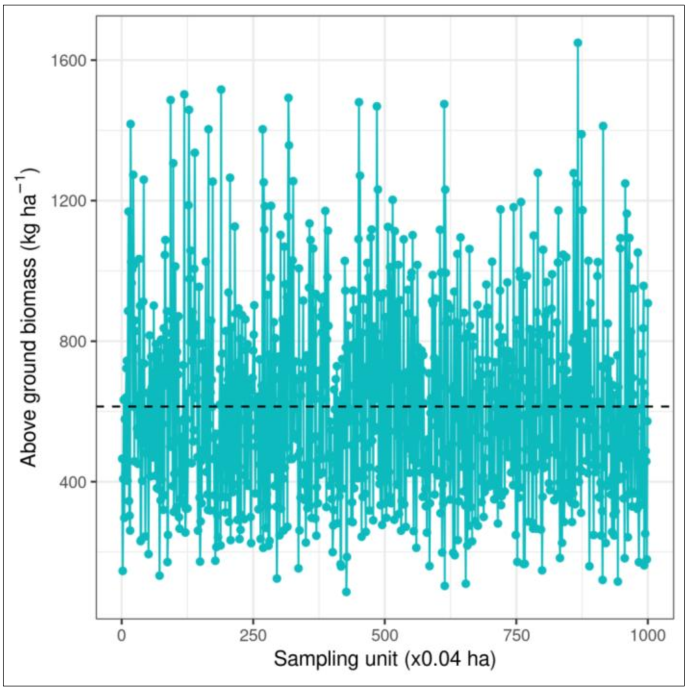

Figure 6. Bootstrap for aboveground biomass from observation plots with the mean bootstrap value (dashed line).

4. Discussion

Stand structure and species composition are important factors for observing the dynamics of an area/ecosystem. The results showed a tree-stand structure that formed an inverse J-curve for all species, specifically for agarwood-producing species (*Aquilaria* sp.). This indicates an ongoing succession process and ecosystem dynamics [21–23]. However, the sample plots were placed in the utilization area (agricultural plantations or home gardens). In addition to the ongoing succession process, this inverse J-curve could also occur because of the age of the plants. Because cultivation usually takes seedlings from another location, they could be from the forest or another nursery of different ages. The adaptation process also affects the growth and development of these seedlings, thus affecting their diameter [24,25]. The distribution of stand structures also indicates that the existence of this species is sustainable [26,27].

The species composition in the plots showed low to medium diversity. This is because the observation plots are placed in plantations (mixed species or monoculture) or home gardens [28,29]. The results of the analysis of importance values, both by PCA and IVI, showed that *Aquilaria* sp. was the most important species in the observed community. The PCA illustrates the contribution of dimension 1, which is quite high in explaining the variance that occurs in the community (Table 3). This eigenvalue is important for understanding the influence of the dimensions (principal components) on the variation in existing data [30]. In addition, the PCA results also showed the possibility of forming three data clusters based on the composition of species and observation plots (Figure 3 and 5). PCA is known to show the possibility of cluster formation by simplifying variables through existing dimensions/principal components [31,32].

The PCA results were also supported by information from the important value index (IVI) calculation. The results of IVI calculations often show important species based on their density, frequency, and dominance. Table 1 shows that the largest basal area was *Cocos nucifera*, but *Aquilaria* sp. was the species with the highest density level and the third largest dominance. This dominance is closely related to the diameter of the stand and density/spacing used [33,34]. Planting distances that are too short can trigger competition to obtain the required nutrients. Thus, individuals who are unable to compete experience stagnation in their growth and development. Ultimately, this will impact the production capacity of stands, especially in agarwood-producing species.

The inhibition of growth and development processes also impacts the aboveground biomass (AGB) produced. However, to date, no research has specifically examined the relationship between biomass and resin production in agarwood-producing species. AGB from monoculture plantation land will generally be smaller when compared to biomass in mixed-species plantations/gardens [35–37]. However, stand age and diameter class also affect the biomass content. Table 5 shows that the monoculture plantation of agarwood-producing species in P5 had a higher AGB value than the other observation plots. This is because the diameter class in this plot tended to be larger than that in the other observation plots. The ability to produce high AGB values in monoculture stands and mixed gardens is promising for the community. The selection of other species planted among the agarwood-producing species can also increase the value of aboveground biomass in community gardens.

From a conservation perspective, agarwood cultivation gardens are expected to be a means of conservation for both species and genetics, especially for local agarwood-producing species. This cultivation activity also needs to be supported by government policies regarding procedures for planting/developing seed sources, especially for local agarwood-producing species, to support the development of sustainable cultivation of agarwood-producing species. In addition, trade-in cultivated products also need to be supported by regulations from relevant technical ministries so that there is a guarantee for local farmers to market their products from agarwood cultivation.

Future studies regarding appropriate nutrient content, inoculation techniques, the relationship between biomass and resin production, and even socio-economic aspects among cultivation farmers are still needed to complement the existing information. However, phylogenetic studies for definite species determination are required. This information will be useful in developing seed sources for agarwood-producing species.

5. Conclusions

We found *Aquilaria* sp. to be an important species in the observed community based on the importance value index and cos2 value from the principal component analysis. The observed community tended to be in the medium category of diversity, with mostly stable conditions. We also found that *Aquilaria* sp. was the dominant species in the observed community, especially at P4 and P5. Biomass calculation estimated an average biomass potential of 600.50 kg ha^{-1}.

Author Contributions

BAP: Methodology, Software, Investigation, Formal Analysis, Writing - original draft; **TDA**: Conceptualization, Methodology, Investigation, Funding acquisition, Validation; **RS**: Conceptualization, Methodology, Investigation, Validation, Writing - Review & Editing; **SJ**: Investigation, Formal Analysis; **SPF**: Investigation, Writing - Review & Editing; **RSM**: Investigation, Writing - Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

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