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Distribution of *Gyrinops versteegii* in varying vegetation structures, soil properties, and microclimates in western part of Flores Island, Indonesia

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Abstract. *Yulistyarini T, Fiqa AP, Budiharta S, Rindyastuti R. 2020. Distribution of* Gyrinops versteegii *in varying vegetation structures, soil properties, and microclimates in western part of Flores Island, Indonesia. Biodiversitas 21: 1800-1808. Gyrinops versteegii* is one of the agarwood-producing tropical plants that is distributed in the Lesser Sunda Islands to Sulawesi, Moluccas (Maluku), and Papua. The natural population of *Gyrinops versteegii* (Gilg.) Domke is widely exploited, making it being listed in CITES Appendix II. Despite largely exploited, information regarding the distribution of *G. versteegii* to reveal the habitat characteristics of its natural population is limited. The aims of the research were (i) to investigate the habitat characteristics of the distribution of *G. versteegii* in term of vegetation community, as well as soil and microclimate variables in its natural habitat in western part of Flores Island, and (ii) to study the relationship between its occurrence and ecological factors. The research was conducted in one community forest and three natural forests in the districts of Manggarai and West Manggarai, Flores Island, East Nusa Tenggara Province. Data on vegetation, soil properties and microclimates were collected by establishing 73 observation plots across the four studied areas. Data were analyzed to reveal vegetation composition and structure where *G. versteegii* occurred, the dispersion pattern, and relationship between its occurrence and ecological factors. Our study revealed that *G. versteegii* populations at four studied areas in Flores Island were distributed in a broad range of habitat characteristics with varying vegetation compositions and structures, canopy covers as well as soil and microclimates variables. The local/metapopulations of *G. versteegii* in these areas can be dispersed in clumped or uniform pattern. Nonetheless, some ecological variables might be important for the abundance of this species including soil texture, soil pH, C organic and Soil Organic Matters (SOM). The results of this study suggest a promising opportunity for the conservation efforts of *G. versteegii* through the possibility of planting this species in various land management including planted in monoculture system, polyculture system (e.g. home garden and agroforestry) as well as reintroduced into species-rich natural forest.

Keywords: Conservation, distribution, ecological, Flores, *Gyrinops versteegii*

INTRODUCTION

Gyrinops versteegii (Gilg.) Domke (or locally known as *gaharu* or *cue'*) is one of agarwood tree species that is distributed in the Lesser Sunda Islands, especially Lombok, Sumbawa, Western Sumba, Alor, and Flores Island to Sulawesi, Moluccas and Papua (Hou 1960; Mulyaningsih and Yamada 2008; Roemantyo and Partomihardjo 2010; Susilo et al. 2014). This species is commonly found in low land primary forest with altitude of 0−800 m above sea level (asl). In Sumbawa Island, *G. versteegii* was found at altitudes of 400−800 m asl from Mount Doro Tambiung in West Sumbawa to Mount Doro Saboke, East Sumbawa (Susilo et al. 2014). In Flores Island, *G. versteegii* was recorded at altitudes of 50-900 m asl (Roemantyo and Partomihardjo 2010) in which the populations can be found including in East Manggarai District (Komar et al. 2014) and Pongkor Community Forest, Manggarai District (Rindyastuti et al. 2019).

Despite the relatively wide distribution of *G. versteegii*, the population of this species indicates a declining trend. As such, this species is listed in CITES Appendix II along with other agarwood species in Indonesia, with export quota restrictions of maximum of 75 tons per year (CITES Trade Database 2018). The population decline is particularly eminent in the provinces of West and East Nusa Tenggara as reported by recent studies (e.g. Mulyaningsih et al. 2014; Mulyaningsih et al. 2017a; Fiqa et al. 2020). The major cause of the population decline in these regions is likely due to overexploitation to extract its resinous wood, often by cutting the standing trees carelessly (Fiqa et al. 2020). In Lombok, the reduction of population of *G. versteegii* in natural forest has started in 2000 (Mulyaningsih et al. 2014), resulting in very limited population with only consisting of two stages (i.e. sapling and seedling), whereas the presence of this species at pole and tree stage were very rare (Mulyaningsih et al. 2017a). Similar finding was reported by Fiqa et al. (2020) in Flores Island that only juveniles up to pole stage of *G. versteegii* were found, while the tree of this species was absent.

For the conservation of *G. versteegii*, there should be efforts to increase its population. One of some proposed strategies is by doing population enrichment, either in the form of enrichment planting on its natural habitat (often termed as reintroduction) or being cultivated outside its natural habitats (e.g. agricultural land, agroforest, and home garden) (Turjaman et al. 2016; Fiqa et al. 2020). Yet, this strategy requires baseline information regarding the biotic and abiotic characteristics (e.g. vegetation community, soil, and climate) that support the survival and growth of *G. versteegii.* Plants are known as a primary component of ecosystem functioning and stability which are affected by environmental factors (Montoya and Raffaelli 2010; Ghaderi et al. 2016). The vegetation growth correlates with some soil properties, vice versa vegetation affects the soil properties (Johnson et al. 2014). Soil controls the hydrological, biological and geochemical cycles in an ecosystem (Smith et al. 2015) and also affects the plant species richness and composition (Keymer and Lankau 2017). In mountainous areas, soil properties (i.e. physical and chemical features) along with topography can play an important role in developing plant communities (Ravanbakhsh and Moshki 2016).

The conservation of *G. versteegii* through planting has been carried out by several entities. For example, since 1996, the Forestry Office of West Nusa Tenggara Province has developed agarwood plantation in Pusuk Protection Forest, Batu Layar District, West Lombok (Mulyaningsih and Yamada 2008). Agarwood plants at pole and tree stages were also found in agroforestry, coffee and cocoa plantations (Mulyaningsih et al. 2017b). Sutomo and Oktavia (2019) recorded *G. versteegii* in some villages in Lombok such as Rarung, Pusung, Senaru, Bebidas and Bugbug in which they were planted along with *Theobroma cacao, Ficus elastica, Albizia chinensis, Dalbergia latifolia* and *Coffea robusta*. Besides in Lombok, *G. versteegii* have also cultivated in Java, Bali, West, and East Kalimantan, East Nusa Tenggara, Gorontalo and Papua (Turjaman and Hidayat 2017). Nevertheless, the agarwood produced from those cultivations is still insignificant to reduce the pressure of agarwood collected from the wild (Komar et al. 2014). One of the problems is likely due to a very slow growth rate of planted *G. versteegii* as indicated in the home garden in Pongkor, Manggarai, Flores (Yulistyarini et al. 2019). Surata and Widnyana (2001) also found that the growth of *G. versteegii* planting in open area results in low survival rate with less than 30% survived. Whilst, Surata and Soenarno (2011) revealed that *G. versteegii* planted in an intercropping system in Rarung, West Nusa Tenggara has better performance because of the existence of shade trees provided by associated plants. Many species of agarwood producing trees are shade-tolerant plants which need shade tree and light intensity around 50% (Beniwal 1989; Surata 2002). All of these imply that the understanding of ecological aspects related to the growth and plant distribution of *G. versteegii* is very important for species conservation and population enhancement in the near future.

Research and surveys, especially to investigate the distribution and ecology of *G. versteegii*, have been carried out, such as in Lombok (Mulyaningsih et al. 2017b; Sutomo and Oktavia 2019), while another study on environmental factors affecting the growth of domesticated *G. versteegii* has been done in Sragen District, Central Java Province (Rawana et al. 2018). However, information about the distribution and ecology of *G. versteegii* in Flores Island is still very limited. Research on the distribution of *G. versteegii* in Flores Island is important to carry out for conservation efforts to complete the data on the species distribution in the Lesser Sunda Islands. The aims of the research were (i) to investigate the habitat characteristics of the distribution of *G. versteegii* in term of vegetation community, as well as soil and microclimate variables in its natural habitat in western part of Flores Island, and (ii) to study the relationship between its occurrence and ecological factors.

MATERIALS AND METHODS

Study period and area

This study was conducted between April 2018 and July 2019 in several fieldworks located in western part of Flores Island, East Nusa Tenggara Province, Indonesia (Figure 1). The study sites were determined based on information about the occurrence of *G. versteegii* natural population which resulted in one community forest (i.e. Pongkor Community Forest, Manggarai District) and three natural forests (i.e. Nggalak Protection Forest in Manggarai District, and Wae Bobok and Puar Lolo Protection Forests, both in West Manggarai District). The study areas have altitudes between 400 to 600 m asl., except Puar Lolo which has an altitude above 800 m asl. All study areas have varying slopes, ranging from flat to 60° and have annual average rainfall around 1500 mm per year with average temperature of 23-30°C and humidity of 68-74% (Table 1).

Table 1. Habitat characteristics of *Gyrinops versteegii* at four study areas in western part of Flores Island, East Nusa Tenggara, Indonesia

Study area	Forest use class	Village, Sub-district, District	Altitude (m asl)	Slope (°)	Stand density (ind./ha)	Tree DBH (cm)	Tree height (m)	Number of plots	Total individual *G. versteegii*
Pongkor	Community forest	Mbau Randang, Pongkor, Manggarai	608-660	30-60	464±140	32.6±5.9	9.6±3.2	9	32
Nggalak	Protection forest	Nggalak, West Reok, Manggarai	484- 604	0-30	5376±2261	36.3±13	23±6.8	32	23
Wae Bobok	Protection forest	Tanjung Boleng, Boleng, West Manggarai	562-638	0-40	3599±1253	45.6±27	22±6	16	7
Puar Lolo	Protection forest	Wae Lolos, Mbeliling, West Manggarai	857-861	0-20	4482±1646	40.8±16	29.9±5.3	16	3

Figure 1. Study areas in Flores Island, East Nusa Tenggara, Indonesia; (1) Pongkor Community Forest, (2) Nggalak Protection Forest, (3) Wae Bobok Protection Forest, (4) Puar Lolo Protection Forest

Data collection

Vegetation sampling

Vegetation analyses were conducted through sampling using a purposive random method. The sampling was carried out by establishing observation plots with size 20 x 20 m for each plot and then within this plot, nested subplots of three different sizes were created. All trees within the 20 x 20 m plot were recorded and measured, while the poles, saplings and groundcovers/ seedlings were recorded within the nested subplots of 10 x 10 m, 5 x 5 m and 2 x 2 m, respectively (Figure 2). The number of plots in each study area is shown in Table 1.

Soil properties and microclimates

The data on soil properties and microclimates were collected from the observation plots of vegetation sampling. Each soil sample was repeated two times. Soil samples were taken with soil depth of 0-20 cm, mixed evenly, and air-dried for analysis of soil texture (pipette method), soil organic matter (SOM;%), organic C (%), total N (%), C/N, P_2O_5 (ppm), and Cation Exchange Capacity (CEC) (me/100 g). The soil analyses were conducted in the Soil Laboratory of Agriculture Faculty at Brawijaya University. While soil moisture (%) and soil pH were measured in the field using soil tester (Takemura DM 5). Microclimates data consisting of temperature (°C) and humidity (%), sunlight intensity (lux) were recorded using thermohygrometer (Dekko 642 N) and lux meter (LX-1102).

Data analysis

Vegetation analysis

The density (D) of all plant species, Important Value Index (IV), and the diversity index were calculated for each study area. The importance value index (IV) was calculated as the sum relative density (RD), relative frequency (RF) and relative dominance (RD). The diversity index calculated included species richness index (S'), Shannon-Wiener species diversity index (H'), Pielou's evenness index (E), and Jaccard similarity index (J'). These indices were calculated as follows (Magurran 1988):

Species richness index (R'):

$$S' = (S-1)/\ln N$$

S : the number of species and
N : the total number of individuals.

Shannon-Wiener species diversity index (H'):

$$H' = -\Sigma\ pi \ln pi' \quad pi = ni/N$$

pi : ratio of the number of individuals in each species to the total number of individuals
ni : number of individual from species-i
N : total number of individual

Pielou's evenness index (E'):

$$E' = H'/\ln (S)$$

H' : Shannon-Wiener Diversity Index
S : total number of species

Jaccard's similarity index (J'):

$$J' = (c/(a+b-c)) \times 100\%$$

c : number of species exist in both plot A and B
a : number of species exist in plot A
b : number of species exist in plot B

The dispersion of *G. versteegii* was determined using Morisita Index(Id) (Krebs 2009):

$$Id = n\frac{\left(\sum x_i^2 - \sum x_i\right)}{\left(\sum x_i\right)^2 - \sum x_i}$$

n : the number of sample in plots
x : the number of individuals in each plot;

Figure 2. Habitat of *Gyrinops versteegii* in Nggalak (A); Wae Bobok (B), Pongkor (C), and Puar Lolo (D), Flores. Note: red arrow is individual of *G. versteegii* which is left by agarwood hunters after the plant being injured

Then its dispersion pattern was determined as follows

$$\mathrm{Mu} = \frac{\chi^2_{0,975} - n + \sum x_i}{\left(\sum x_i\right) - 1}$$

$$\mathrm{Mc} = \frac{\chi^2_{0,025} - n + \sum x_i}{\left(\sum x_i\right) - 1}$$

Mu : morisita index for uniform dispersion patterns
Mc : morisita index for clump dispersion patterns
$X^2_{0,975}$: value of Chi square table with confidence interval 97.5%
$X^2_{0,025}$: value of Chi square table with confidence interval 2.5%

Then the standart degree of Morisita as calculated using following formula:

$$Ip = 0{,}5 + 0{,}5\left(\frac{Id - Mc}{n - Mc}\right) \quad \text{If } Id \geq Mc > 1$$

$$Ip = 0{,}5\left(\frac{Id - 1}{Mc - 1}\right) \quad \text{If } Mc > Id \geq 1$$

$$Ip = -0{,}5\left(\frac{Id - 1}{Mu - 1}\right) \quad \text{If } 1 > Id > Mu$$

$$Ip = -0{,}5 + 0{,}5\left(\frac{Id - Mu}{Mu}\right) \quad \text{If } 1 > Mu > Id$$

If Ip = 0 =distribution pattern is random, Ip<0 = distribution pattern is uniform, and Ip>0= distribution pattern is clumped.

Relationship between species occurrence and ecological factors

The relationship between species occurrence of *G. versteegii* and ecological factors was analyzed using Principal Component Analyses (PCA). The PCA was conducted using Past 3 software by incorporating data of individual numbers of *G. versteegii*, individual number of woody species (tree, pole, and sapling), soil properties, and microclimates.

RESULTS AND DISCUSSION

Vegetation structure and composition of the habitat of *Gyrinops versteegii*

The four studied areas of *Gyrinops versteegii* habitat vary in vegetation structure and composition. Based on stand density, vegetation community in Pongkor forest has the lowest density and abundance of large trees (Table 1).

This area is remnant forest with small extent and is located within a large rice field outer of Ruteng Nature Recreation Park (Yulistyarini et al. 2019). The three other forests, which are natural forests, had higher density of stands than Pongkor. Nggalak Forest had the highest stand density, but the diameters of stands were lower than those in Wae Bobok and Puar Lolo forests.

The plant composition and importance values index (IVI) shows distinct differences across vegetation stages and forest locations (Table 2). In Pongkor and Puar Lolo, the tree vegetation was dominated by few species, while in Nggalak and Wae Bobok, there were no tree species that tend to dominate the vegetation. In Pongkor, *Gyrinops versteegii* dominated the tree vegetation with IVI of 140.8%, followed by *Aleurites moluccanus* and *Canarium vulgare* with IVI of 87.3% and 72%, respectively. In Puar Lolo, *Fraxinus griffithii* was the dominant species with IVI of 124.4%. This plant is frequently found as a pioneer species in mountain areas, more commonly above 1.100 meters. In Nggalak forest, *Lagerstroemia duperreana* had the highest IVI (33.7%) while in Wae Bobok, *Syzygium* sp. had the highest IVI (36.1%). Yet, the IVI of both species in both locations is not far different from the other tree species.

Table 2. The top five plant species having the highest Importance Value Index (IVI) across the four forests of *Gyrinops versteegii* natural habitat in Flores Island, Indonesia

Plant species	IVI (%)			
	Pongkor	**Nggalak**	**Wae Bobok**	**Puar Lolo**
Tree				
Gyrinops versteegii	140.8	-	-	-
Aleurites moluccanus	87.3	-	-	-
Canarium vulgare	72.0	-	-	-
Lagerstroemia duperreana	-	33.7	-	-
Aglaia sp.	-	18.4	-	-
Burckella sp.	-	15,5	-	-
Calophyllum soulatri	-	13.5	-	-
Mitrephora polypyrena	-	12.2	-	-
Syzygium sp.	-	-	36.1	-
Syzygium acuminatissimum	-	-	34.0	-
Buchanania arborescens	-	-	33,6	-
Ficus benjamina	-	-	25.6	-
Syzygium racemosum	-	-	22.3	-
Fraxinus griffithii	-	-	-	124.4
Turpinia sphaerocarpa	-	-	-	43.1
Polyosma integrifolia	-	-	-	23.7
Myrsine sp.	-	-	-	22.1
Nephellium sp.	-	-	-	9.1
Pole				
Canarium vulgare	49.7	-	-	-
Gyrinops versteegii	49.4	-	-	-
Croton argyratus	20.8	-	-	-
Syzygium littorale	17.8	-	-	-
Archidendron pauciflorum	17.6	-	-	-
Syzygium racemosum	-	23.0	-	-
Myristica guatteriaefolia	-	20.5	-	-
Mitrephora polypyrena	-	20.0	-	-
Canarium asperum	-	13.3	-	-
Tabernaemontana macrocarpa	-	13.1	-	-
Croton caudatus	-	-	54.5	-
Syzygium sp.	-	-	30.7	-
Buchanania arborescens	-	-	21.9	-
Calophyllum soulattri	-	-	16.3	-
Stemonurus scorpioides	-	-	15.2	-
Litsea sp.	-	-	-	35.0
Tarenna fragrans	-	-	-	26.4
Garcinia sp.	-	-	-	25.3
Turpinia sphaerocarpa	-	-	-	24.9
Polyosma integrifolia	-	-	-	19.4
Sapling				
Croton argyratus Blume	26.3	-	-	-
Garcinia balica	25.3	-	-	-
Gyrinops versteegii	20.9	-	-	-
Sterculia coccinea	14.0	-	-	-
Canarium vulgare	12.1	-	-	-
Syzygium racemosum	-	19.2	-	-
Aglaia sp	-	16.7	-	-
Cleistanthus oblongifolius	-	12.0	-	-
Burckella sp	-	11.8	-	-
Glochidion zeylanicum	-	11.7	-	-
Croton caudatus	-	-	58.9	-
Knema sp.	-	-	42.2	-
Syzygium sp.	-	-	24.4	-
Stemonurus scorpioides	-	-	16.0	-
Buchanania arborescens	-	-	15.0	-
Garcinia sp.	-	-	-	56.5
Tarenna fragrans	-	-	-	46.3
Tabernaemontana sphaerocarpa	-	-	-	24.5
Litsea sp.	-	-	-	17.1
Rubiaceae	-	-	-	16.9
Groundcover/seedling				
Selaginella plana	27.0	-	-	-
Kyllinga brevifolia	16.5	-	-	-
Kyllinga sp	9.6	-	-	-
Melastoma malabathricum	9.4	-	-	-
Oplismenus compositus	8.4	-	-	-
Aglaia tomentosa	-	43.9	-	-
Canarium asperum	-	13.7	-	-
Eranthemum nervosum	-	13.0	-	-
Coffea canephora	-	8.3	-	-
Heritiera littoralis	-	5.6	-	-
Calophyllum soulatri	-	-	22.5	-
Garcinia sp.	-	-	21.4	-
Stemonurus scorpioides	-	-	15.2	-
Derris elliptica	-	-	14.4	-
Acer laurinum	-	-	8.6	-
Selaginella sp.	-	-	-	31.6
Ruellia sp.	-	-	-	18.9
Carex baccan	-	-	-	18.0
Pinanga coronata	-	-	-	16.6
Tarenna fragrans	-	-	-	12.4

There are no species that very dominant at poles stage across the four forests of *G. versteegii* habitat. In Pongkor, *G. versteegii* had the highest IVI at poles stage, while *Syzygium racemosum, Myristica guatteriaefolia,* and *Mitrephora polypyrena* were the top tree species with the highest IVI in Nggalak forest. There was no dominance at sapling stage in Pongkor and Nggalak, but it was in Wae Bobok and Puar Lolo. *Croton caudatus* and *Knema* sp. were the dominant saplings in Wae Bobok, while *Garcinia sp.* and *Tarenna fragrans* were the dominant saplings in Puar Lolo. At groundcover/seedling stage, there were species with high level of dominance. At this stage, *Aglaia tomentosa* had the highest IVI in Nggalak (43.9%), while *Selaginella* sp., which is the fern group and grows mostly in mountanious and moist area, showed the highest important value in Pongkor (27.4 %) and Puar Lolo (31.6%). Besides ferns, there were also some species of graminoids from Cyperaceeae family such as *Kyllinga brevifolia* and *Carex baccan.* C. *baccan* was found in wet moist area such as Puar Lolo (altitude 800 m asl.). A species that has a high IVI means that the species has more control over the area, especially in utilizing resources or it has better ability to adjust to the surrounding environment, and also it indicates how the species play a role in an ecosystem (Sundarapandian and Swamy 2000).

The biodiversity indices differed among growth stages and the four studied areas (Table 3). Nggalak has the highest species number, Shannon-Wiener diversity index, and richness index of three stages, namely tree, pole, and sapling. On the other hand, Pongkor has the lowest species number, diversity index, and richness index on the three stages (i.e. tree, pole, and sapling). However, diversity index of ground cover/seedling is the highest in this forest. Generally, the diversity of the four studied areas is at medium level with index of $1<H'<3$ to high with $H'>3$.

Similarly, the richness of these areas is categorized as high (> 5), except the richness of trees in Pongkor which is categorized as low as it only reaches 1.2.

Similarity Index (J') describes the level of similarity in structure and composition of species in all communities with the comparison within the range of values between 0% to 100% (Magurran 1988). A value of 100% indicates similarity and a value of 0% indicates inequality. Based on the similarity index of four forests indicate plant communities in all forests are different (Table 4). The highest similarity is shown by vegetation in Wae Bobok and Nggalak with similarity index of 27.5%. This is understandable as both forests have relatively similar altitudes and are located in a closer distance to coastal areas with parental geology that is largely composed of limestone rocks.

The results on vegetation analysis of the four habitats of *G. versteegii* in western part of Flores Island (Tables 1-4) suggest that this species can grow in a broad range of habitats with varying vegetation compositions and floristic structures. It means that these species do not require specific association with particular vegetation, for example as in the case of Indian sandalwood (*Santalum album*) (Nurochman et al. 2018). This is an important finding for population enhancement efforts as it implies that *G. versteegii* can be planted in varying vegetation conditions, whether it is cultivated in monoculture plantation system, planted along with other species in polyculture system, such as agroforestry, or even reintroduced into its natural habitat with high species richness.

Table 4. The matrix of Similarity Index (J') between habitats of *Gyrinops versteegii* in Flores Island, Indonesia

	Pongkor	Nggalak	Wae Bobok	Puar Lolo
Pongkor		13.37%	6.13%	2.875%
Nggalak			27.5%	15.75%
Wae Bobok				27.47%
Puar Lolo				

Table 3. Biodiversity index of each growth stage in the four studied areas of *Gyrinops versteegii* in Flores Island, Indonesia

Growth stage	Indices	*G. versteegii* habitat			
		Pongkor	Nggalak	Wae Bobok	Puar Lolo
Tree	Species number	3	58	29	22
	Diversity Index	1.0	3.7	2.9	2.2
	Evenness Index	0.9	0.9	0.9	0.7
	Richness Index	1.2	10.7	5.9	4.7
Poles	Species number	22	67	36	35
	Diversity Index	2.7	3.7	2.5	3.1
	Evenness Index	0.9	0.9	0.8	0.9
	Richness Index	5.2	11.8	5.8	5.5
Sapling	Species number	41	64	31	30
	Diversity Index	3.3	3.8	2.8	3.2
	Evenness Index	0.9	0.9	0.8	1.0
	Richness Index	8.6	10.8	6.5	5.9
Groundcover	Species number	76	80	53	54
	Diversity Index	3.5	3.1	3.2	2.9
	Evenness Index	0.8	0.7	0.8	0.7
	Richness Index	10.2	12.3	9.2	8.6

Table 5. Ecological variables of the habitats of *Gyrinops versteegii* in Flores Island, Indonesia

	Pongkor	Nggalak	Wae Bobok	Puar Lolo
T (°C)	27.7-32,8	24.8-29.8	23.7-24.3	23.5-25.2
RH (%)	56-79	59-87	70-72	70-82
Light Intensity (Lux)	272-2160	229.7-1862	14.6-182	114.8-329.1
Alt (m asl)	608.5-659.4	484.1-603.7	562-638	857-862
pH	6.4-6.8	5.9-6.3	6.2-6.8	5.8-6.8
Soil moisture (%)	59-77	30-75	15-43	15-95
C organic (%)	2.44-3.66	3.18-5.18	2.92-5.38	3.29-3.96
N total (%)	0.2-0.3	0.35-0.48	0.25-0.45	0.24-0.37
C/N	11-12	9-13	10-12	10-17
SOM (%)	4.22-6.33	5.5-9.22	4.54-9.31	5.69-6.84
P_2O_5 (ppm)	2.9-3.7	3.15-9.37	0.73-0.76	0.75-0.8
CEC (me/ 100 g)	13.3-17.54	41.78-58.37	27.43-44.19	22.5-35.93
Sand (%)	14-21	4-8	25-52	13-22
Dust (%)	51-66	24-50	24-47	40-67
Clay (%)	20-34	45-72	24-41	20-43

The habitat of *G. versteegii* in Nggalak, Wae Bobok, and Puar Lolo have medium to high H index for trees, indicating a relatively good forest cover. Conversely, Pongkor has relatively low H index for trees, suggesting an open forest canopy and higher disturbance level. These findings imply that *G. versteegii* is able to grow in habitat with varying canopy covers, from a relatively open area to closed forest with dense canopy which provides shade for this species. This is important trait of *G. versteegii* as many seedlings of plant and understory species are suppressed under dense forest canopy (Qian et al. 2016), yet it is not the case for *G. versteegii*.

The ability of *G. versteegii* to grow in various vegetation compositions and canopy covers is a good aspect for its conservation. In the context of biodiversity conservation in general, vegetation diversity is an important parameter in an ecosystem as the more diverse the species in an ecosystem, the better and more stable the ecosystem (Isbell et al. 2011). However, despite the overall vegetation richness in Nggalak forest, the natural regeneration of *G. versteegii* in this area indicates a problem as the adult stage (i.e. tree) was absent (Fiqa et al. 2020). This differs from the case of Pongkor in which *G. versteegii* population in these areas has quite good regeneration structure as it is composed of four plant stages, from seedlings to trees (Rindyastuti et al. 2019) despite the low level of vegetation richness.

Dispersion pattern of *G. versteegii* in its habitat

The study on dispersion pattern is important to explain the biological aspects of populations of *G. versteegii* in relation to environmental factors. Based on the calculations of Morisita dispersion index (Id), *G. verteegii* in Pongkor has Morisita dispersion index of 1.02 and Mc (Morisita index for cluster distribution patterns) of 1.38, while the value of Ip (standard degree Morisita) is 0.47. Since Id ≥ Mc> 1.0 and Ip> 0, therefore it can be concluded that the dispersion pattern of *G. versteegii* in Pongkor is clumped. Similarly, the dispersion pattern of *G. versteegii* in Wae Bobok is also clumped (Ip=0.49). However, *G. versteegii* shows uniform dispersion in Nggalak (Ip= -0.09) and Puar Lolo (Ip=-0.11).

The dispersion pattern of *G. versteegii* in the four studied areas in Flores differs among each other. In Pongkor and Wae Bobo, this species was clumped, while in Nggalak and Puar Lolo it is uniformly dispersed. Other agarwood producing tree (*Aquilaria* sp.) showed clumped distribution in Sumatra and Kalimantan (Soehartono and Newton 2000) and in Kutai National Park (Pribadi 2009). Differences in dispersion patterns indicate that the four studied areas have different ecological conditions. Also, this might be caused by anthropogenic factors including overexploitation at the tree stage or the possibility of limited number of sampling plots (Soehartono and Newton 2000).

Relationships between ecological factors and the occurrence of *G. versteegii*

Table 5 shows the ecological variables of the habitat of *G. versteegii* in the four studied areas in Flores Island. In general, the observation plots of *G. versteegii* are at elevation of 500-900 m asl with slope ranging from 0-60°. The four forests have air temperature (T) ranging from 23-30° C, relative humidity (RH) around 70-73% and sunlight intensity of 100-10000 lux. The soil pH ranges from 6- 6.7 (rather acid until neutral) and soil moisture 30-70%. Based on soil chemical properties, the population of *G. versteegii* grows in fertile soil with C organic ranges from 3-4 % which is categorized as high. These forests are covered by quite thick litter. These soils consist of medium Nitrogen (0.25-0.4%), medium C/N (10-12) and low phosphor (0.7-5%). The cation exchange capacity (CEC) in the studied area is categorized as low until very high (15-50 me/100 g). Soil texture varies across the four studied areas in which Nggalak has the highest content of clay, while the others have the highest content of dust.

The results of Principal Component Analysis (PCA) show that the fourteen ecological variables observed can be grouped into four main components indicated by eigenvalue > 1. These four component factors explained 81.2% of the variability of all observed variables (the first component is 45.7%, the second component factor is 15.1%, the third component factor is 12.4% and the fourth component factor is 7.9%) (Table 6). This indicates that the first component of variables provides relatively greater information than the other component of variables in relation to habitat conditions of *G. versteegii*. The results of clustering using PCA show that the occurrence of *G. versteegii* is more influenced by C organic and SOM (Figure 3). There is a strong correlation between the content of C organic and SOM, indicated by the sharp angle formed by C organic and SOM (Figure 3). The presence of *G. versteegii* is also related to soil pH and dust content. This can be seen from the distribution of this species points that are close to the line of the variable soil pH and dust content.

Table 6. Eigenvalue and value of ecological variables of the habitats of *Gyrinops versteegii* in Flores Island, Indonesia

	PC 1	**PC 2**	**PC 3**	**PC 4**
Eigenvalue	6.39	2.12	1.74	1.12
Variance (%)	45.63	15.13	12.41	7.98
Cumulative (%)				81.15
Variable				
Soil pH	**-0.35**	0.00	0.03	-0.26
soil moisture	-0.10	**0.59**	0.15	0.15
Carbon	0.31	-0.11	**0.41**	0.09
Nitrogen	**0.36**	-0.07	0.09	0.16
C/N	-0.16	-0.11	**0.58**	-0.15
Soil Organic Matter (SOM)	0.31	-0.12	**0.41**	0.09
Phosphor	0.21	**0.41**	-0.12	0.05
Cation Exchange Capacity (CEC)	**0.36**	-0.06	-0.12	-0.13
Sand	-0.20	**-0.47**	0.01	-0.25
dust	-0.32	0.13	-0.05	0.37
clay	**0.36**	0.17	0.03	-0.14
Light Intensity (LI)	-0.11	0.36	**0.36**	-0,50
altitude (alt)	-0.20	-0.10	**0.31**	**0.60**
Individual number of woody species (IN)	-0.13	0.16	0,18	-0.04

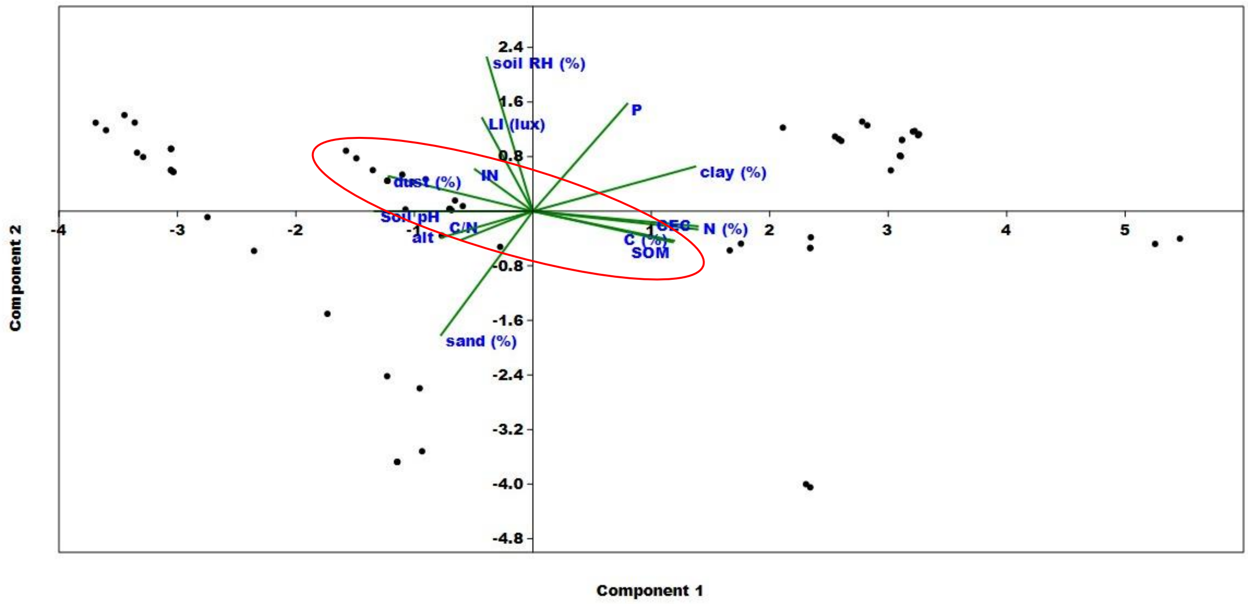

Figure 3. Result of PCA to determine the relationship between the occurrence of *Gyrinops versteegii* and ecological factors. Black dotes are individuals of *G. versteegii*; red circle is the relationship between plant and ecological factors

The relationship between the occurrence of *G. versteegii* and soil dust content indicates that *G. versteegii* population grows at intervals of dust content of 34-56%, as recorded from this study. Nonetheless, location with dust content about 56% has higher abundance of *G. versteegii* than locations with dust content close to 34%. Soils with high dust content have a loamy texture class. The analysis on soil physical properties show that all studied areas have clay until dusty clay loam texture with sufficient soil nutrient. Soil pH also relates to the abundance of *G. versteegii*. Soil pH in the habitat of *G. versteegii* in the four forests has ranged between 6-6.7. Location with pH close to neutral (6.7) has higher abundance of *G. versteegii* than locations with lower pH (close to 6) which is rather acidic. Generally, nutrients are easily absorbed by plant roots at pH neutral. The preference of *G. versteegii* to grow in fertile soil indicates that this species needs sufficient nutrients for its growth. However, high nutrient soil does not always cause an increase of abundance of *G. versteegii*. This is shown by the negative relationship between individuals of *G. versteegii* and C organic and SOM (Figure 3). C organic value in this study ranges between 3 and 4%, meaning that location with C organic content close to 4% has lower abundance of *G. versteegii* than locations with organic content close to 3%.

The relationship between the occurrence of *G. versteegii* and ecological factors in western part of Flores Island as shown in this study is different from the same research conducted in Lombok Island. In Lombok, light intensity is the main factor affecting the occurrence of *G. versteegii* with light intensity reaches up to 2147.6 lux (Mulyaningsih et al. 2017b). Sutomo and Oktavia (2019) state that *G. versteegii* has strong relationship with soil pH, soil moisture, light intensity, and air temperature. The difference in ecological factors affecting the occurrence of *G. versteegii* in these two regions is likely due to different treatments in regard to regeneration aspect. In Lombok, the study was carried out on cultivation areas, such as agroforestry, cocoa, and coffee plantations, in which *G. versteegii* were planted by communities, while this research in western part of Flores was conducted in natural forests in which *G. versteegii* population was naturally regenerated. Usually, in cultivation area, light intensity becomes the main limiting factor for plant growth. Naturally, *G. versteegii* requires lower light intensity which can be obtained from natural forest habitats and is considered as a shading tolerant species (Rawana et al. 2018*;* Mulyaningsih et al. 2015). In this study, light intensity is likely not as a limiting factor since the light intensity of the four forests did not show obvious differences which ranged between 100 and 900 lux. For example, Pongkor forest has the highest light intensity among other three forests as the canopy is opened due to human interventions in the form of agricultural activities, as well as animal fodder and firewood collection (Rindyastuti et al. 2019; Yulistyarini et al. 2019). Yet, it is predically suitable for the growth of *G. versteegii* that regenerate naturally.

In conclusion, our study revealed that *G. versteegii* populations at four studied areas in western part of Flores Island were distributed in a broad range of habitat characteristics with varying vegetation compositions and structures, canopy covers as well as soil and microclimates variables. The local/metapopulations of *G. versteegii* in these areas can be dispersed in clumped or uniform pattern. Nonetheless, some ecological variables might be important for the abundance of this species including soil texture, soil pH, C organic and Soil Organic Matters (SOM). The results of this study suggest a promising opportunity for the conservation efforts of *G. versteegii* through the possibility of planting this species in various land management including planted in monoculture system, polyculture system (e.g. homegarden and agroforestry) as well as reintroduced into species-rich natural forest.

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