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Autecology and morphological properties of sandalwood (*Santalum album*) in Pidie District, Aceh, Indonesia

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Abstract. *Nurochman D, Matangaran JR, Santosa G, Suharjito D, Sari RK. 2018. Autecology and morphological properties of sandalwood (Santalum album) in Pidie District, Aceh, Indonesia. Biodiversitas 19*: *406-412.* IUCN Red List (1998) reported that *Santalum album* L. as an endangered species. Studies on autecology, association, and the utilization of sandalwood on its natural habitat becomes important to perform conservation of the species. This research was conducted in Teungku Dilaweung Village, Pidie District, Province of Aceh. Vegetation analysis was conducted to determine the population structures. Distribution pattern was analyzed using Morisita Index (Id) and Chi-square test, while interspecific association pattern was determined through contingency table, Jaccard Index (JI) and variance-ratio (VR) test. Observation and analysis of physical and chemical properties of soil, topography, and microclimate were done to identify ecological factors affecting the presence of sandalwood. The study showed that the highest abundance at tree level (IVI>100%) was obtained by *Syzygium cumini* with a density of 15 trees/ha. *S. album* was found to have clumped distribution pattern with an Id value of 2.258 and $\chi^2_{compute}$ of 62.571. *S. Album* has an interspecific association with two species i.e.: *Syzygium cumini* ($\chi^2_{compute}$ of 5.104 and JI of 0.846) and *Ziziphus oenopolia* ($\chi^2_{compute}$ of 6.516 and JI of 0.833) with VR of 0.474. Interspecific association indicated that *S. album* has strongly associated with *Syzygium cumini* and *Ziziphus oenopolia*. Morphological characters and habitat properties of sandalwood in research site has a similarity to the Province of NTT.

Keywords: Association, autecology, contingency, sandalwood

INTRODUCTION

Sandalwood (*Santalum album* L.) is a hemiparasite plant native to Indonesia. In the wild population, the species occurs from the eastern of Java, Island of Madura, Bali, Rote, Wetar, Sawoe to Sumba, and has been traded to China and India through Malacca Strait since 17th century (Blusse and Veen 2007; Fuller et al. 2011; Kumar et al. 2012). The presence of sandalwood in Province of Aceh makes its the only region with potential sandalwood in Sumatra Island. Sandalwood is known by the local people of Aceh as "Ceundana" in Aceh Besar District or "Bak Cin" in Pidie District. Sandalwood is also known as the royal plant because of its high economic value and easy to generate cash money (Jensen and Meilby 2010). The stem and root of sandalwood are used as raw material for producing aromatic oil, craft industry, and various incenses (Kumar et al. 2011; Brand et al. 2012; Page et al. 2012).

The population of sandalwood in Indonesia continues to decrease. According to ITTO (2010), its population in the Province of East Nusa Tenggara (NTT) in 1997 consisted of 51,417 mother trees and 199,523 seedlings, whereas in 1987 consisted of 176,949 mother trees and 388,003 seedlings. The International Union for Conservation of Nature (IUCN) Red List (1998) reported that sandalwood was categorized as vulnerable (Kurniawan et al. 2015). It means that there is a possibility of extinction in nature of 10% within 100 years. Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2010 included sandalwood, which is Red sandalwood and African sandalwood in Appendix II. It means that the species still could be traded based on quota (Kurniawan et al. 2015; Rajan and Jayalaksmi 2017).

Sandalwood is a unique forest product in term of cultivation since it has low survival rate up to 20% (Surata 2010). Regarding to its growth, sandalwood needs host plants as a nutrient supplier. Data and information related to the specific ecology of sandalwood in its natural habitat or known as autecology of sandalwood become very important to conserve and cultivate the species (Donovan and Puri 2004). The relationship between sandalwood and ecological factors together will affect its physiology of growth and heredity (Kurniawan et al. 2013). The autecology study of sandalwood in Indonesia was only conducted in Province of NTT by Riswan (2001) and Kurniawan et al. (2013). Therefore, this study was intended to analyze sandalwood autecology in Province of Aceh, Indonesia.

MATERIALS AND METHODS

Study area

This study was conducted in Tengku Dilaweung Village, Muara Tiga Subdistrict, Pidie District, Province of Aceh, Indonesia (Figure 1).

Materials and tools

The objects of this research are the stand of sandalwood (*Santalum album* L.) and other trees in the sampling plot. Research tools were used included Garmin GPS 76 CSX, compass, measurement tape, plastic rope, clinometer, haga hypsometer, scissor, parang machete, and stationary.

Procedures

Data was collected through the method of line transect of 15 plots as shown in Figure 1 (ITTO 2011; Durairaj and Kamaraj 2013; Pereki et al. 2013; Huish et al. 2015). Data collection included: morphological characteristic of sandalwood tree, trees composition, edaphic factor, topography, and microclimate. Sandalwood tree level follows the SNI No: 01-5008.6 (1999), which has a diameter (dbh) ≥ 15 cm. Data of sandalwood utilization rate were obtained by secondary data from BPS of Aceh Province (2005).

Data analysis

Quantitative data of sandalwood were obtained by calculating the Important Value Index (IVI) of Relative Density (RDe), Relative Frequency (RF), and Relative Dominance (RDo). Sandalwood distribution pattern was measured using Morisita Index of Dispersion (Id). Association between sandalwood tree and other tree species adopted the method of interspecific association performed using contingency table of 2x2 was shown in Table 1. The contingency table was based on the species absence-presence binary data, and further, the value of Chi-square (χ^2) and variance-ratio (VR) test were computed. Measurement of interspecific association level was performed using Jaccard Index (Elpino-Campos et al. 2007; Sofiah et al. 2013). The shape of crown, tree architecture, shape and size of sandalwood leaves were noted to know its morphological variations.

Morisita Index is an index of population distribution measurement which has independent characteristic towards the population density and sample size, using an equation:

$$Id = n\left[\frac{\sum x2 - \sum x}{(\sum x)2 - \sum x}\right]$$

Where :
Id = Morisita index
n = Number of plots
$\sum x$ = Total number of plots
$\sum x^2$ = Sum of square for total plots

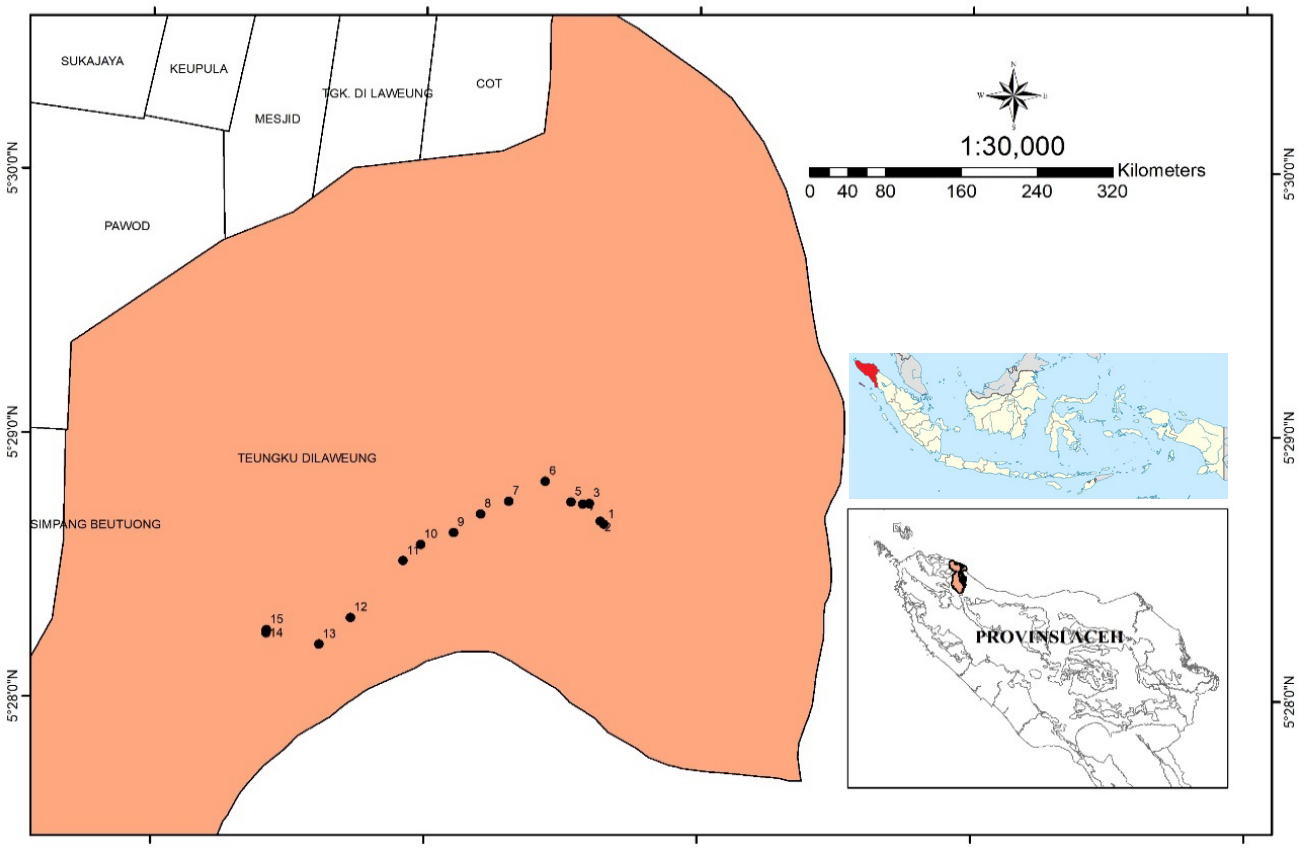

Figure 1. Research site and sampling plot points in vegetation analysis of sandalwood in Tengku Dilaweung Village, Muara Tiga Subdistrict, Pidie District, Province of Aceh, Indonesia. Note: Point 1 (N 5º28'39.97" and E 95º52'39.53")

Table 1. The species association using contingency table of 2x2

Species B / *Species A*	Presence	Absence	
Presence	A	B	m=a+b
Absence	C	D	n=c+d
	r=a+c	s=b+d	N=a+b+c+d

Jaccard Index (JI) shows the proportion of sample plot number which has the presence of one of both species of all plot numbers, using an equation by Ludwig and Reynolds (1988):

$$JI = \frac{a}{a+b+c}$$

Where :
JI = Jaccard index
a = Species A and B are presents
b = Species A is present, species B is absent
c = Species A is absent, species B is present
d = Species A and B are absent

RESULTS AND DISCUSSION

Morphological properties

Sandalwood tree in Pidie District has the orthotropic monopodial stem. Following Roux architectural model, the tree has plagiotropic branching with 2-3 branches from the similar base branch. It is a small tree with height less than 6 m, diameter of the stem (dbh) < 20 cm, no buttress root with the dominance of lateral root. Leaf single, oppositely arranged with intersecting one another; leaf blade elliptic, flat edge, sharp-pointed tip but sometimes blunt, small size with average 5.6 x 2.6 cm, yellowish green to green, flexible with a length-width ratio of 2.3: 1. Inflorescences terminal or axillar. Fruit drupe, flesh and peel green when young, then turn brown to black when ripe, exocarp, mesocarp, and endocarp has a hard layer (Figure 2). Boroh (2001) mentioned that sandalwood tree with yellow heartwood has better quality than brown or black heartwood. Sandalwood is slow growing tree with average circumference increment at breast height only reaches 1-2 cm per year (Surata and Idris 2001). Some sandalwood trees were flowering and bearing fruits, while some others were not during field observation. Based on the result of an interview with respondents that collected sandalwood, sandalwood tree commonly starts flowering and bearing fruits from March to June or in the dry season every year. This condition is different from the flowering and fruit-bearing season of sandalwood in Province of NTT, that is from March to April and September to October (Buharman et al. 2011).

Structure and abundance

The number of sandalwoods obtained from the result of vegetation analysis was 227 stand with the structure of stand dominated by the seedling level (seedling, sapling, and pole) of 225 stands and mother tree level (dbh ≥ 15 cm) of 2 stands. Population structure in research site is presented in Figure 3. Abundance analysis of sandalwood was presented in the Important Value Index (IVI) (Table 2).

Table 2. The IVI calculation of each species

Species	RDo	RF	RDe	IVI
Tree				
Santalum album	19.087	22.222	22.222	63.532
Syzygium cumini	71.984	66.667	66.667	205.317
Phyllanthus acidus	8.929	11.111	11.111	31.151
Pole				
Santalum album	34.772	37.500	31.579	103.851
Syzygium cumini	38.929	25.000	36.842	100.771
Phyllanthus acidus	11.711	18.750	15.789	46.250
Senna siamea	5.755	6.250	5.263	17.269
Tamarindus indica	8.833	12.500	10.526	31.859
Sapling				
Santalum album	38.500	33.333	49.438	121.272
Syzygium cumini	28.700	25.000	23.596	77.295
Phyllanthus acidus	13.311	13.889	10.112	37.312
Senna siamea	7.161	11.111	5.618	23.890
Vitex pinnata	5.785	5.556	4.494	15.835
Tamarindus indica	3.033	5.556	3.371	11.959
Azadirachta indica	3.510	5.556	3.371	12.437
Seedling				
Santalum album	78.475	40.741	78.475	197.691
Syzygium cumini	9.865	33.333	9.865	53.064
Phyllanthus acidus	8.969	14.815	8.969	32.752
Senna siamea	1.794	7.407	1.794	10.995
Vitex pinnata	0.897	3.704	0.897	5.497

Note: RDo= Relative Dominance; RF= Relative Frequency; RDe= Relative Density; IVI= Important Value Index \

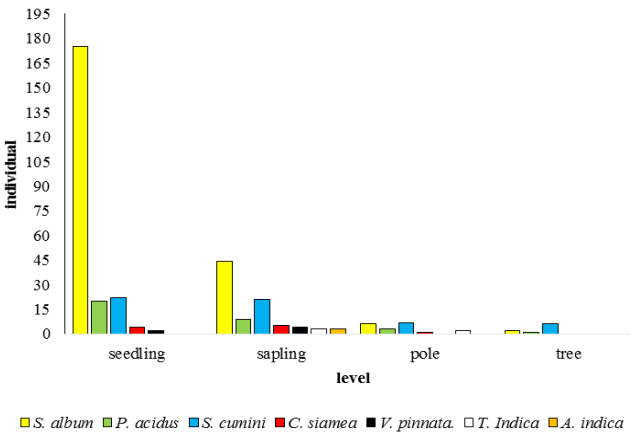

Figure 3. Structures of species at each level

Figure 2. Sandalwood tree and model architecture (left); young fruit (right-above); seedling (right-midle); stockpilling (right-down); stem cross-section (right-down)

Based on vegetation analysis showed that a total number of seedling and mother trees in research site was higher than 21 villages in Timor Tengah Selatan District, Province of East Nusa Tenggara (ITTO 2010). Average individual number of those 21 villages was 42.8 stands, with the highest number of sandalwood was found in 2 villages, namely: Oelbubuk Village of 250 stands and Haunobenak Village of 275 stands. It shows that production potential of sandalwood in research site is better than most villages in Timor Tengah Selatan District. Based on the calculation of IVI, the highest IVI value is presented by seedling (197.691), followed by sapling (121.272), and pole (103.851), while the level of mother trees, *Syzygium cumini* had the highest IVI value of 205.317 (Table 2). This finding is caused by most sandalwood has been harvested by the local people for sandal sapwood to gain economic value.

The value of relative abundance of sandalwood stand indicated that there is direct ecological impact because sandalwood is harvested by the local people in accordance with its stand structure (Ticktin 2004). Furthermore, Sirait (2005) explained that the abundance of each species at each level showed an interaction and association between species which is an implementation form of ecological science in natural resource management.

Distribution pattern and interspecific association

Based on Morisita Index of Dispersion (Id), sandalwood distribution pattern was 2.258 (Id>1) with the $\chi 2$ compute value of 62.571 and $\chi 2$ table (14;0.05) value of 23.685. It showed that its distribution pattern was not random with standardized Morisita Index (Id) of 0.543 and confirmed that sandalwood has clumped distribution pattern. Interspecific association test between sandalwood and seven species associated was done using Chi-square test, Jaccard Index, and variance-ratio test (Table 3). Jaccard Index (JI) was applied to know the proportion of the amount of total pair plot species or one of the species tested, while variance-ratio (VR) test was done to know whether the index of species pair has a positive or negative association.

The sandalwood has strong association with two species, namely *Syzygium cumini* and *Ziziphus oenopolia*. It means that the presence of sandalwood has a linkage with the presence of *Syzygium cumini* and *Ziziphus oenopolia* with Jaccard Index (JI) value of 0.846 and 0.833, respectively. Value of VR obtained from the association between sandalwood and other seven species was 0.474 or less than 1 which indicated a negative association. Negative association means that competition of each species will occur for their survival, includes the need for living space to get food source and sunlight. In term of development, sandalwood needs host plant for supplying its nutrients, particularly N, P and amino acid, while Ca and K is taken from its root system. The nutrient is taken by sandalwood using haustorium in the form of root nodules attached to the host plant root (Surata and Idris 2001). This specific interaction explains that sandalwood has specific host plant, particularly *Syzygium cumini* and *Ziziphus oenopolia*.

Habitat properties

The research site is an arid open area dominated by grass and shrub at the altitude of ± 95 m asl. with the average rainfall of ± 1.522 mm per year and the average temperature of 24°C–32°C (BPS 2014). Based on the Land Cover Map of the Directorate General of Forest Planology and Environmental Governance (2015), research site is included savanna with climate type E according to Schmidt and Ferguson. Soil type in research site according to USDA system is classified as ultisol order equivalents red-yellow podzolic and hydro morph soil. Based on the analysis of two soil samples in research site showed that the soil has clay loam texture with chemical properties as listed in Table 4.

Sandalwood habitat in research site has a similarity to its habitat in Province of NTT, such as land cover dominated by savanna or shrubland with D and E climate type according to Schmidt and Ferguson, the altitude of 50-1.200 m asl. and rainfall of 625-1.625 mm/year (Buharman et al. 2011). The condition of soil fertility shows that soil contains low organic matter and neutral acidity (pH). The content of C-organic level, N-Total, C/N ratio, and P was included in low category with high a content of Ca element. The value of soil cation exchange capacity (CEC) was included in moderate category which was obtained from the result of colloid adsorption of cation type Ca^{2+}. Therefore, the level of organic matter content was low, cation inside the soil was able to be detained by soil colloid thus it can store the required nutrient. It is in accordance with the statement of Surata (2006) and Kurniawan et al. (2013) that sandalwood in Province of NTT grows in shallow rocky soil, has neutral-alkaline (pH), moderate N level, a moderate to high level of P (P_2O_5) with soil type of latosol (or ultisol according to USDA) and has a loam texture. Soil chemical properties in research site were relatively similar to the result of soil analysis in five villages in Timor Tengah Selatan District: Kuanfatu, Anin, Haunobenak, Oelbubuk and Eonbesi, particularly the soil texture which is dominated by loam and clay, neutral pH, low N-Total and moderate CEC (ITTO 2011).

Sandalwood utilization

Based on the interview with respondents, it is known that sandalwood in Tengku Dilaweung Village of Muara Tiga Subdistrict has existed for a long time and grows naturally (not produced by cultivation). Abu Kasim, a local forest commander (Panglima Adat Uteun) explained that "Bak Cin has existed since the first generation of his family (his grandfather) became the local forest commander". Utilization of sandalwood by the local people is performed when there was a market demand by using simple tools such as parang machete, hoe, and a sack with an informal work organization (anyone may take sandalwood). Utilization of sandalwood product is commonly in the form of sandal sapwood directly sold to the intermediary trader and local collector without any advanced processing. The sandal sapwood is referred to small round wood of less than 15 cm in diameter. Data of sandal sapwood production in Aceh Province from 2003 to 2015 are presented in Figure 4.

Table 3. Interspecific association test between sandalwood and other species

Analysis	Species						
	S. cumini	***S. siamea***	***P. acidus***	***V. pinnata***	***T. indica***	***A. indica***	***Z. oenoplia***
χ^2 compute	5.104 *	0.682	0.227	0.839	3.068	0.642	6.516 *
Jaccard Index	0.846	0.231	0.308	0.182	0.077	0.083	0.833

Note: * signifikan on $\alpha_{0.05}$; df $_1$ (χ^2_{table} =3.841)

Table 4. Value of soil chemical compounds

pH (H_2O)	C-Org	N-Total	C/N	P	Ca	CEC
7.11	4.13 %	0.32 %	12.91	2.37 ppm	44.46 cmol/kg	45.54 cmol/kg

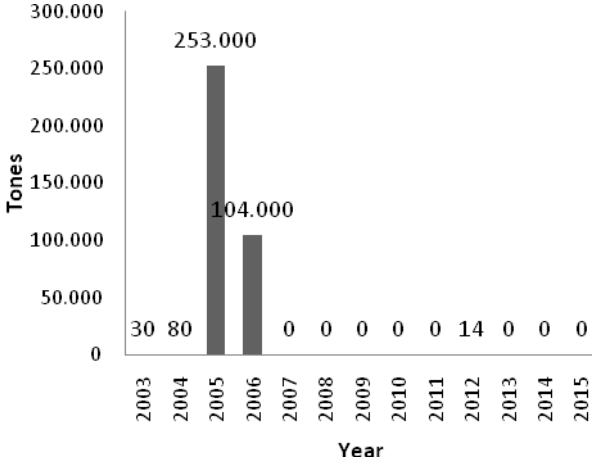

Figure 3. The utilization rates of sandalwood in Province of Aceh (source: BPS Aceh Province 2003-2016 processed)

The high economic value of sandalwood boosts uncontrolled exploitation. As the need for sandalwood worldwide is extremely high, sandalwood market opportunity is highly opened (Ramya 2010). Total sandalwood utilization in Aceh Province from 2003 to 2015 reached 357,124 ton or 29,760 ton per year. The highest sandalwood production occurred in 2005 after the tsunami which reached 253,000 ton (BPS 2005).

In conclusion, morphological and habitat properties of sandalwood in research site have a similarity to the Province of NTT. Sandalwood has clumped distribution pattern and strongly associated with *Syzygium cumini* and *Ziziphus oenopolia* which are expected to be the host plants. Based on the stand structures dominated by the seedling level (seedling and sapling) with a very low level of pole and mother tree, sandalwood stand is classified into a young stand with a high level of utilization.

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