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Typology of native species as the shade tree for merbau (*Intsia bijuga*) plantations in Papua, Indonesia based on ecological species group

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Abstract. *Sirami EV, Marsono Dj, Sadono R, Imron MA. 2019. Typology of native species as the shade tree for merbau (*Intsia bijuga*) plantations in Papua, Indonesia based on ecological species group. Biodiversitas 20: 43-53.* Ecological species group is an ecological principle that can be used as a reference in determining the potential native tree species of Papua as the shade trees for merbau in the mixed forest plantations. This research was conducted to identify the potential native trees as the shade for merbau plantation in Papua. The data collection used systematic line technique with hypothetical plot and sampling tree as the plot center. The Dice Index was used to analyze the level of association between merbau and the neighboring trees as well as to serve as a basis for determining ESG and Important Value Index was used to analyze the level of tree dominance. The main potential shade trees consisting of *Pometia coriacea* Radlk., *Lepiniopsis ternatensi* Valeton, *Spathiostemon javensis* Blume, *Palaquium amboinense* Burck., and *Pimelodendron amboinicum* Hassk. Whereas complementary and alternative potential shade consisting of *Haplolobus lanceolatus* H.J.Lam ex Leenh, *Haplolobus celebicus* H.J.Lam, *Horsfieldia laevigata* Warb., *Horsfieldia irya* (Gaertn.)Warb. *Prunus costata* Kalkman, *Sterculia macrophylla* Vent., *Dysoxylum mollissimum* Blume, *Pertusadina multifolia* (Havil.) Ridsdale, *Streblus elongatus* (Miq.) Corner and *Geijera salicifolia* Schott. The main shade trees possessed a main function for rendering shade toward younger merbau in the plantation area. Meanwhile, complementary and alternative shade trees were intended for increasing soil nutrient availability and optimizing microclimate surround merbau seedlings.

Keywords: Ecological species group, Gunung Meja, merbau plantations, native species, shade trees, Papua

INTRODUCTION

Merbau (*Intsia bijuga* (Colebr.) Kuntze) is a native species of New Guinea that has an ecological role in the structure of Papua's lowland forests, the economic and socio-cultural role of local communities (Sadono et al. 2014). However, forest destruction (Sirami et al. 2018; Vincent et al. 2015; Margono et al. 2014) and merbau massive logging (Sirami et al. 2018; Newman and Lawson 2005), have caused damage to the habitat of merbau and serious threats (Sirami et al. 2018; Marler 2015) to the dynamics of its population in the future.

One of the alternative to overcome these threats is to build local species plantations (Sirami et al. 2018; Barua et al. 2014; Jacovelli 2014; Bremer and Farley 2010). However, merbau is a semi-tolerant species that has a slow growth rate that needs medium shades to grow appropriety. Merbau needs more light for germination, but the medium light intensity is also required for regeneration and adult tree development because of its semi-tolerant species (Sirami et al. 2018). Thus, the plantations environment must be adjusted to its growing behavior in the naturale forest. Therefore, the accuracy of shade tree selection is one of the most important silvicultural factors in the development of merbau plantations in Papua.

The ecological principles that can be used to select shade trees are complementary interaction and facilitation of production (Raharjo et al. 2009). Species with right ecological combinations are those that have complementary properties (Haggar and Ewel 1997). Complementary properties of trees can reduce competition and allow efficient use of the most restrictive resources such as water, nutrients and light in the plant community (Lamb 2011) that productivity is high. This principle is known as the competitive production principle. The principle of production facilitation is the interaction between species where a particular species helps the growth of others directly (Vandermeer 1989). Species attributes that can be used as possible indicators for planting in mixed plantations include tolerance and intolerance, high growth rates, canopy structure, leaf phenology, root depth and phenology (Kelty 1992; Haggar and Ewel 1997; Nguyen et al. 2014).

The population of trees as the source of selection must be native tree species because they naturally have the interspecific association with merbau. The interspecific association leads to the formation of ecological groups by several species of trees with the same life forms because they have the same way of adaptation to habitat factors and the existence of environmental affinity (Mueller-Dombois and Ellenberg 1974; Su et al. 2015; Spies and Barnes 1985). The same way of adaptation to habitat factors is an indicator that species in the same ecological group can be domesticated outside their natural habitat. Thus, the ecological species group (ESG) can be applied in the arrangement of mixed plantations (Su et al. 2015; Jalilvand et al. 2007; Lan et al. 2012; Li et al. 2008). According to Nguyen et al. (2014), the growth strategy of species that grow in natural forests can be a clue to the role they might play on plantations including whether they are tolerant, intolerant or growing in forest sub-strata.

Some advantages of using native tree species are that they have better adaptation and they facilitate the acceptance of local communities (Peque and Holscher 2014; Nichols and Vanclay 2012; Bremer and Farley 2010) if the management of plantations is the local community-based. Besides being productive, the shade trees must also be able to continue diffuse light, have the canopy structure that is easily regulated, not a source of disease, absorb a lot of CO_2, increase soil nutrients, contribute to biological diversity, and prevent erosion (Prawoto et al. 2006; Tscharntke et al. 2011; Sepulveda and Carrillo 2015).

Currently, there are no studies that have reported of native Papuan tree species that have potential to become the shade trees for merbau in plantations. This study was conducted to identify the potential native species as the shade trees for merbau plantations in Papua.

MATERIALS AND METHODS

Study area

This research was conducted at Gunung Meja Nature Tourism Park of Manokwari (GMNTPM), West Papua, Indonesia (Figure 1) (134° 03'17"-134 ° 04'05" W and 0°51'29-0°52'59" S), in 2016 for 9 months. GMNTPM is one of the protected areas and plays a very significant role for forest ecology studies. A part from being a natural habitat for merbau, GMNTPM is a rough forest prototype for the Papua region. Merbau habitat at GMNTPM has an area of ± 264 ha of craggy soil surface (Sirami et al. 2018, 2016; Sadono et al. 2014), from 460.25 ha in the entire area. This area is relatively flat to wavy; the temperature under the forest canopy in the dry season is around 29-31°C. Rainfall for the last 13 years ranges from 1429 mm to 3419 mm, while the sunshine ranges from 444 to 745 h (Statistics Agency of Manokwari Regency 2016). The soil texture is sandy clay soil with a soil surface depth of less than 50 cm. Forest canopy ranges from 40 to 98%, with slopes of 2-40%, the altitude of 70-170 m above sea level (Sirami et al. 2018; Sadono et al. 2014).

Research procedures

The initial survey was carried out using the merbau distribution map in GMNTPM that had been made previously. The data was performed using the systematic line technique with hypothetical plot and sampling tree as the plot center. This technique was the result of modification of several existing vegetation analysis techniques for the needs of plant autecology research in the Papua lowland forest that have high tree density.

In this technique, the observation line was made systematically with a line distance of 30 m. The observation line was only as a guide to do the observations. Whenever merbau trees were found in and around the observation line, a quadratic sampling unit of 400 m^2 was made, with the position of at least one merbau tree as the center of the plot. All trees with diameters of ≥ 10 cm in the observation plot were recorded by name of species, number of stands, size of diameter and total height.

For the association analysis, the arranged tree data in the presence-absence binary table was 2 x 2, namely if there was the species *i* in the plot *n* it is written 1, and if nothing it is written 0.

Data analysis

The stand structure was analyzed using important value index (Curtis and McIntosh 1951), and the level of association was analyzed using Dice Index (Ludwig and Reynolds 1988) as follow:

$$\text{Dice Index (DI)} = \frac{2a}{2a + b + c}$$

Note: a = the frequency of merbau trees and the tree species *i* found in the n-th plot, b = the frequency of merbau trees found with non tree species *i* in the *n* plot, c = the frequency of non-merbau trees and non tree species *i* found in the *n* plot. If DI = 0, then there is no association between merbau trees and trees species *i*, if DI = 1 then there is an association.

The level of association and dominance of neighboring trees in the forest structure is used as a reference to determine the ecological species group and potential shade trees for merbau.

RESULTS AND DISCUSSION

Structure, species composition and association levels of neighboring trees

The number of neighboring trees recorded in 181 sampling units were 2735 stands or 17.66 stands per sampling unit, consisting of 120 native species, 1 introduced species from 86 genera and 38 families (Table 1). The tree diameters ranged from 10-130 cm with total height ranged from 2-46 m.

Merbau habitat in GMNTPM has a normal vegetation structure (Table 1). According to Leslie (1966), the concept of normal forest originated from the concept of yield regulation. One of the requirements to achieve sustainability of forest products is the inverse-J shaped stand structure. The inverse-J pattern is only applicable when viewed as whole tree vegetation, but actually it is composed of structural patterns of each different species. Frieswyk et al. (2007) point out that the dominant species are a group that plays a role in determining the shape of the plant community structure, but the behavior of each species is very uneven. Normal structure is an indication that the regeneration process in the forest is going well.

The species of neighboring trees with the highest association level are *Pometia coriacea*, *Lepiniopsis ternatensi*, *Spathiostemon javensis*, *Palaquium amboinense*, *Pimelodendron amboinicum*, *Haplolobus lanceolatus*, *Haplolobus celebicus*, *Horsfieldia laevigata*, *Horsfieldia irya*, *Prunus costata*, *Sterculia macrophylla*, *Dysoxylum mollissimum*, *Pertusadina multifolia*, *Streblus elongatus* and *Geijera salicifolia*. We termed these species as the most associable tree species (MATS) because they have better association capabilities with merbau stands.

According to Su et al. (2015), positive associations occur because between trees indicate the distribution of resources, broad niches and overlapping. The level of such associations was an indication that only MATS were more likely to evolve in opposition to merbau on the rocky soil in GMNTPM. Zhang et al. (2012) argue that rocky soil causes only certain species to grow. This fact showed broad adaptability and environmental tolerance (Ismaini et al. 2015; Sirami 2013) of MATS.

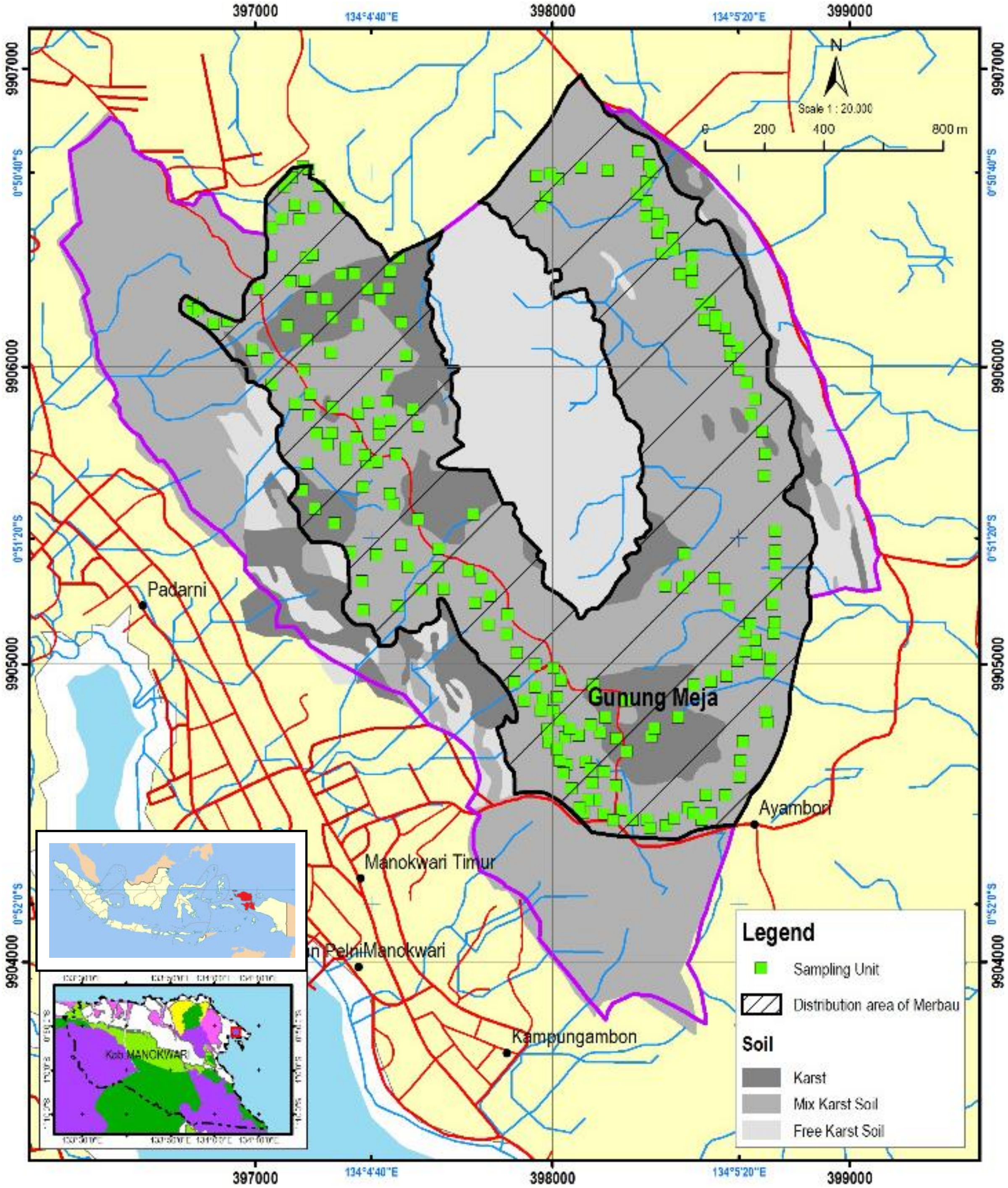

Figure 1. Reseach site in Gunung Meja Nature Tourism Park of Manokwari (GMNTPM), West Papua Province, Indonesia

MATS is more dominant in the forest structure (Table 1), because of the broader control of growing space, more often around the merbau stand and has an individual density per ha which is relatively high compared to the other 106 species. This domination shows the ability to adapt to the rocky soil at GMNTPM and a better biological fitness level. The biological fitness level of MATS is indicated by a fairly good reproductive ability such as the relatively large number of fruits and seeds, the anatomical structure and morphology of the seeds which strongly supports the mechanical, physical and biological germination and dispersion process. As well as, *Pometia coriacea*, *Lepiniopsis ternatensis*, *Spathiostemon javensis*, *Palaquium amboinense*, *Pimelodendron amboinicum*, *Haplolobus lanceolatus*, *Haplolobus celebicus*, *Horsfieldia laevigata*, *Horsfieldia irya*, *Prunus costata*, *Sterculia macrophylla* and *Dysoxylum mollissimum* the process of dispersing of these species is assisted by frugivorous animals of the bird and mammals group at GMNTPM (Sirami et al. 2018).

Table 1. Species composition, stand structure and association levels of the neighboring trees

Species	Family	Association		Domination	
		Dice index (DI)	Levels	IVI	Levels
Aceratium oppositifolium DC.	Elaeocarpaceae	0.09	Low	2.42	Low
Actinodaphne nitida Teschner	Lauraceae	0.04	Low	1.10	Low
Aglaia odorata Lour.	Meliaceae	0.02	Low	0.52	Low
Aglaia spectabilis (Miq.) S.S.Jain & S.Bennet	Meliaceae	0.11	Low	2.25	Low
Agrostistachys borneensis Becc.	Euphorbiaceae	0.01	Low	0.24	Low
Alstonia macrophylla Wall. ex G.Don	Apocynaceae	0.03	Low	0.62	Low
Alstonia scholaris (L.) R. Br.	Apocynaceae	0.05	Low	1.01	Low
Anisoptera costata Korth.	Dipterocarpaceae	0.01	Low	0.20	Low
Antiaris toxicaria Lesch.	Moraceae	0.08	Low	1.99	Low
Archidendron parviflorum Pulle	Leguminosae	0.03	Low	0.95	Low
Artocarpus altilis (Parkinson ex F.A.Zorn) Fosberg	Moraceae	0.03	Low	1.07	Low
Bridelia sp.	Phyllanthaceae	0.01	Low	0.25	Low
Buchanania arborescens (Blume) Blume	Anacardiaceae	0.18	Low	4.61	Low
Calophyllum inophyllum L.	Clusiaceae	0.13	Low	5.90	Low
Cananga odorata (Lam.) Hook.f. & Thomson	Annonaceae	0.01	Low	0.29	Low
Canarium hirsutum Willd.	Burseraceae	0.06	Low	1.62	Low
Canarium indicum L.	Burseraceae	0.05	Low	1.35	Low
Carallia brachiata (Lour.) Merr.	Rhizophoraceae	0.04	Low	1.00	Low
Celtis latifolia (Blume) Planch	Ulmaceae	0.09	Low	1.82	Low
Celtis philippensis Blanco	Ulmaceae	0.1	Low	1.73	Low
Cerbera floribunda K.Schum	Apocynaceae	0.01	Low	0.54	Low
Chionanthus macrocarpus Blume	Oleaceae	0.06	Low	2.01	Low
Cinnamomum burmanni (Nees & T.Nees) Blume	Lauraceae	0.05	Low	1.40	Low
Citronella latifolia (Merr.) R.A.Howard	Cardiopteridaceae	0.01	Low	0.34	Low
Cleistanthus oblongifolius (Roxb.) Mull.Arg.	Phyllanthaceae	0.03	Low	0.76	Low
Cleistanthus papuanus (Lauterb.) Jabl.	Phyllanthaceae	0.01	Low	0.15	Low
Cryptocarya palmerensis C.K.Allen	Lauraceae	0.06	Low	1.37	Low
Crysophyllum sp.	Sapotaceae	0.01	Low	0.25	Low
Diospyros hebecarpa A.Cunn. ex Benth	Ebenaceae	0.03	Low	0.58	Low
Diospyros papuana Valeton ex Bakh.	Ebenaceae	0.09	Low	1.84	Low
Diospyros polyalthioides Hierns	Ebenaceae	0.01	Low	0.15	Low
Diospyros sp.	Ebenaceae	0.11	Low	2.41	Low
Dracontomelon dao (Blanco) Merr. & Rolfe	Anacardiaceae	0.01	Low	0.15	Low
Drypetes acuminata P.I.Forst.	Putranjivaceae	0.02	Low	0.81	Low
Dysoxylum mollissimum Blume	Meliaceae	0.4	Medium	11.27	Medium
Dysoxylum octandrum (Blanco) Merr.	Meliaceae	0.05	Low	1.42	Low
Dysoxylum mollissimum subsp. *molle* (Miq.) Mabb	Meliaceae	0.08	Low	2.34	Low
Elaeocarpus angustifolius Blume	Elaeocarpaceae	0.15	Low	3.03	Low
Endospermum moluccanum (Teijsm. & Binn.) Kurz	Euphorbiaceae	0.07	Low	2.13	Low
Ficus benjamina L.	Moraceae	0.09	Low	1.75	Low
Ficus chrysolepis Mig.	Moraceae	0.03	Low	0.54	Low
Ficus sp.	Moraceae	0.06	Low	1.08	Low
Ficus variegata Blume	Moraceae	0.01	Low	0.34	Low
Ficus nervosa subsp. pubinervis (Blume) C.C.Berg	Moraceae	0.24	Low	6.68	Low
Flacourtia inermis Roxb.	Salicaceae	0.03	Low	0.81	Low
Flindersia pimenteliana F.Muell.	Rutaceae	0.06	Low	0.58	Low
Garcinia picrorhiza Miq.	Clusiaceae	0.02	Low	4.81	Low
Garcinia sp.	Clusiaceae	0.05	Low	1.11	Low
Geijera salicifolia Schott	Rutaceae	0.44	Medium	14.18	Medium
Guioa sp.	Sapindaceae	0.02	Low	0.53	Low
Gymnacranthera farquhariana (Hook.f. & Thomson) Warb.	Myristicaceae	0.06	Low	1.37	Low
Gynotroches axillaris Blume	Rhizophoraceae	0.02	Low	0.41	Low

Haplolobus celebicus H.J.Lam	Burseraceae	0.36	Medium	9.82	Medium
Haplolobus lanceolatus H.J.Lam ex Leenh	Burseraceae	0.48	Medium	20.95	Medium
Harpullia arborea (Blanco) Radlk.	Sapindaceae	0.11	Low	2.35	Low
Homalium foetidum Benth.	Salicaceae	0.02	Low	0.30	Low
Horsfieldia iriana W.J.de Wilde	Myristicaceae	0.01	Low	0.26	Low
Horsfieldia irya (Gaertn.) Warb.	Myristicaceae	0.43	Medium	11.28	Medium
Horsfieldia laevigata Warb.	Myristicaceae	0.47	Medium	18.37	Medium
Horsfieldia parviflora (Roxb.) J.Sinclair	Myristicaceae	0.01	Low	0.47	Low
Horsfieldia sylvestris Warb.	Myristicaceae	0.02	Low	0.58	Low
Inocarpus fagifer (Parkinson) Fosberg	Leguminosae	0.02	Low	0.43	Low
Intsia palembanica Miq.	Leguminosae	0.05	Low	3.31	Low
Ixora sp.	Rubiaceae	0.04	Low	1.16	Low
Kokoona ochracea Merr.	Celastraceae	0.01	Low	0.28	Low
Koordersiodedron pinnatum (Blanco) Merr.	Anacardiaceae	0.24	Low	6.56	Low
Lepiniopsis ternatensis Valeton	Apocynaceae	0.79	High	48.61	High
Litsea ladermanii Teschner	Lauraceae	0.05	Low	1.28	Low
Litsea timoriana Span.	Lauraceae	0.01	Low	0.18	Low
Lunasia amara Blanco	Rutaceae	0.03	Low	1.00	Low
Maasia glauca (Hassk.) Mols, Kessler & Rogstad	Annonaceae	0.02	Low	0.67	Low
Maasia sumatrana (Miq.) Mols, Kessler & Rogstad	Annonaceae	0.09	Low	1.87	Low
Macaranga aleuritoides F.Muell.	Euphorbiaceae	0.01	Low	0.28	Low
Mallotus philippensis (Lam.) Mull.Arg.	Euphorbiaceae	0.12	Low	4.16	Low
Mallotus ricinoides (Pers.) Mull.Arg.	Euphorbiaceae	0.02	Low	0.49	Low
Mallotus sp.	Euphorbiaceae	0.26	Low	16.21	Medium
Mangifera minor Blume	Anacardiaceae	0.03	Low	1.27	Low
Maniltoa browneoides Harms	Leguminosae	0.02	Low	0.42	Low
Mastixiodendron pachyclaudos (K.Schum.) Melch.	Rubiaceae	0.09	Low	2.80	Low
Medusanthera laxiflora (Miers.) R.A.Howard	Stemonuraceae	0.08	Low	2.24	Low
Melicope elleryana (F. Muell.) T.G.Hartley	Rutaceae	0.01	Low	0.17	Low
Micromelum minutum Wight & Arn	Rutaceae	0.01	Low	0.25	Low
Mimusops sp.	Sapotaceae	0.02	Low	0.67	Low
Morinda citrifolia L.	Rubiaceae	0.01	Low	0.24	Low
Myristica gigantea King	Myristicaceae	0.06	Low	1.87	Low
Myristica papuana Scheff	Myristicaceae	0.01	Low	0.24	Low
Nauclea sp.	Rubiaceae	0.11	Low	2.27	Low
Ochrosia sp.	Apocynaceae	0.01	Low	0.15	Low
Osmoxylon globulare Philipson	Araliaceae	0.05	Low	1.31	Low
Palaquium amboinense Burck	Sapotaceae	0.7	High	35.37	High
Pertusadina multifolia (Havil.) Ridsdale	Rubiaceae	0.38	Medium	9.20	Medium
Picrasma javanica Blume	Simaroubaceae	0.02	Low	0.58	Low
Pimelodendron amboinicum Hassk.	Euphorbiaceae	0.86	High	53.13	High
Pisonia umbellifera (J.R. Forst. & G. Forst.) Seem.	Nyctaginaceae	0.22	Low	6.83	Low
Planchonella sp.	Sapotaceae	0.01	Low	0.17	Low
Planchonella obovata (R.Br.) Pierre	Sapotaceae	0.06	Low	1.30	Low
Polyscias nodosa (Blume) Seem.	Araliaceae	0.01	Low	0.34	Low
Pometia acuminata Radlk.	Sapindaceae	0.01	Low	0.23	Low
Pometia coriacea Radlk.	Sapindaceae	0.87	High	52.93	High
Pometia pinnata J.R.Frost. & G.Frost.	Sapindaceae	0.12	Low	4.35	Low
Premna corymbosa Rottler & Willd.	Lamiaceae	0.03	Low	0.90	Low
Prunus costata (Hemsl.) Kalkman	Rosaceae	0.35	Medium	12.81	Medium
Pterygota horsfieldii (R.Br.) Kosterm.	Malvaceae	0.04	Low	1.26	Low
Rapanea sp.	Primulaceae	0.08	Low	2.22	Low
Saccopetalum sp.	Annonaceae	0.03	Low	0.67	Low
Spathiostemon javensis Blume	Euphorbiaceae	0.69	High	37.84	High
Stemonurus javanicus Blume	Stemonuraceae	0.23	Low	6.79	Low
Sterculia macrophylla Vent.	Malvaceae	0.32	Medium	10.20	Medium
Sterculia parkinsonii F.Muell	Malvaceae	0.01	Low	0.26	Low
Sterculia shillinglawii F.Meull	Malvaceae	0.15	Low	3.81	Low
Sterculia urceolata Sm.	Malvaceae	0.03	Low	0.60	Low
Streblus elongatus (Miq.) Corner	Moraceae	0.31	Medium	9.18	Medium
Syzygium malaccense (L.) Merr. & L.M.Perry	Myrtaceae	0.01	Low	0.52	Low
Terminalia canaliculata Exell.	Combretaceae	0.02	Low	0.31	Low
Terminalia complanata K.Schum.	Combretaceae	0.12	Low	2.39	Low
Theobroma cacao L.	Malvaceae	0.01	Low	0.60	Low
Tristaniopsis sp.	Myrtaceae	0.03	Low	0.77	Low
Virola surinamensis (Rol. ex Rottb.) Warb.	Myristicaceae	0.25	Low	5.97	Low
Vitex cofassus Reinw. ex Blume	Lamiaceae	0.01	Low	0.17	Low
Ziziphus angustifolia (Miq.) Hatus. ex Steenis	Rhamnaceae	0.01	Low	0.16	Low

Note: Low if DI = < 0.31; Medium if DI = 31-0.60; High if DI = > 0.60

Significant correlations among density, dominance and Dice index ($p < 0.01$), and between density and dominance ($p < 0.01$) from the MATS were presented Table 2. Ecologically, the relationships explained that even though the association level was determined only based on presence-absence data, the dominant stand structure drove the high association level between the MATS and merbau.

Density and dominance were indicators that the MATS are the dominant species in GMNTPM compared to 105 other species. The similar pattern was also found in China's Mount Daiyun National Park that the dominant tree species such as *Pinus taiwanensis*, *Phyllostachys edulis, Fokienia hodginsii, Pinus massoniana* and *Rhododendron simiarum* also had positive associations with other species (Su et al. 2015).

The stand structure of the MATS showed the ability to compete better to get space to grow above the ground. Grime (1979) explains that the ability of competition is a function of growth space, activity, distribution in a particular space and time of each plant to get much power depending on a combination of plant characteristics.

Competitiveness was an indicator that the MATS adapted better than other species. Adaptation of species to specific habitat conditions determines the distribution of different species along the environmental gradient according to time and place (Garzon-Lopes 2014; Whittaker et al. 1975). This ability is caused by differences in niches, species distribution limits (Guo et al. 2017; Lai et al. 2009), and good growth performance of each species under different environmental conditions (Jaime et al. 2015).

Although the MATS were distributed more evenly, there was no indication of the dominance of a single species. For example, *Pometia coriacea* had more control over growing space, but its density was lower than that of *Pimelodendron amboinicum.* Meanwhile, *Lepiniopsis ternatensis* and *Spathiostemon javensis* were more dominant in strata B and C even though they were less dominant in growing space. Coexistence or association is also determined by the limitation of the tree species spread which can prevent local dominance by a single species (Bohlman et al. 2008; Garzon-Lopez 2014).

The potential shade tree species for merbau plantations

Based on adaptability, the MATS are considered potential as the shade trees for merbau. The MATS and merbau are in the similar ESG based on their adaptability to rocky soil. They also show the similarity of ESG with the same way of adaptation through its dominance in the forest structure. ESG is a group of plants that have the same life forms and grow in the similar habitat or have similar habitat (Su et al. 2015; Spies and Barnes 1985; Abella and Covington 2006), and this is a quantitative definition. Qualitatively, Swaine and Whitmore (1988) divide tropical rain forest plants into two ESGs: pioneers and non-pioneers. Pioneers are the types of plants that germinate under the forest gaps whereas non-pioneers are plants that growth under the canopies. ESG is an ecological potential that can be applied in structuring mixed plantations (Su et al. 2015; Jalilvand et al. 2007; Li et al. 2008; Lan et al. 2012) by combining two or several types that have complementary properties (Raharjo et al. 2009), because they have right ecological combinations (Haggar and Ewel 1997).

Quantitatively, both merbau and the MATS are one ESG on the basis from similar habitat preferences in limestone forests. The MATS are also native Papuan plants in the same bio-geographic region as merbau. The MATS are non-pioneering ESG group while merbau represents the pioneer ESG because of its semi-tolerant nature. Therefore, the MATS as a species of group can be used as the shade trees for merbau in plantations. Su et al. (2015) explain that the dominant species in the same ESG can be successfully planted in mixed plantations because they have complementary biological properties. They found these indications in two predominant species of *Pinus massoniana* and *Cunninghamia lanceolata* in Daiyun National Park of China. Positive interaction or facilitation between neighboring trees can increase tree growth and protection from extreme environmental conditions, such as reducing the direct effects of radiation, preventing drying of soil surfaces, controlling the microclimate (Wright et al. 2014; Holmgren et al. 1997, Classen et al. 2010, Montgomery et al. 2010). Further, Su et al. (2015) explain that China succeeded in building the most extensive plantations in the world but was less productive because it relied on a single species. In other words, the use of mixed species from ESG similarity is one way to increase forest plantations productivity.

Table 2. Correlation among association levels, density and dominance of the most associable trees species (MATS)

		Density	Dominance	Dice index
Density	Pearson correlation	1	.877**	.933**
	Significance (2-tailed)		.000	.000
	N	122	122	122
Dominance	Pearson correlation	.877**	1	.756**
	Significance (2-tailed)	.000		.000
	N	122	122	122
Dice index	Pearson correlation	.933**	.756**	1
	Significance (2-tailed)	.000	.000	
	N	122	122	122

Note: **.Correlation is significant at the 0.01 level (2-tailed)

Another requirement that the MATS must have as the shade trees is to have a faster growth rate than merbau trees and have potential economic value. Table 3 shows that the growth rate of merbau is slower than the MATS. Merbau is heavy, hard with density of 0.63-1.04 gr/m^3 at 15% moisture content, in strong class I-II (Martawijaya et al. 1989) and long-lived. Environmental and genetic factors cause the slow growth of merbau tree. Ecologically, the slow growth of merbau is due to adaptation to competition with other trees. Biologically, long-term hardwoods generally have higher wood density and behavior (West 2014). High density and stiffness of wood is an indicator that the growth of xylem to the outside and inside of the stem is slow, as an adaptation to growing under the shade of forest. This is what causes the diameter growth of merbau trees to be slow. Another ecological clue explained by Johns (1986), that the ancestors of merbau and others dominant trees actually adapted to open areas because of the great natural disasters in New Guinea in the past. Perhaps, because of the adaptation caused when merbau grow under the shade, then its growth becomes slow.

The shade trees for merbau must have a faster growth rate (Table 3) because the shade trees must be planted first to a certain height before planting merbau. The aim is to make it available to the newly planted merbau and to improve soil conditions. According to Chen et al. (2015) and De Deyn et al. (2008), fast-growing can increase soil fertility. Nonetheless, this does not mean that pioneer or invasives species can be used as shade trees because these trees are short-lived, and generally lack economic value. Until its pole level, merbau still needed shade even it was found that several merbau stands were aborting leaves when the field data collection was conducted. Merbau trees that are planted later will be harvested for long-term rotation, for example in 35-40 years, while the shade trees are expected to be harvested before harvesting merbau to cover the initial costs of plantation development. Shade trees must have ecological, economic and socio-cultural functions, therefore invasive and pioneer species are not properly used as merbau shade trees.

In West Papua dan Papua province, the price of commercial woods in class I are range from 2 million to 4 million rupiahs per m^3. In addition, the mixed forest wood, prices range from 1 million to 3 million rupiahs per m^3. However, the prices of woods always fluctuate following supply and market demand in each regency or city.

Table 3. Growth rate and potential economic value of the most associable trees species (MATS)

The most associable trees species	DBH growth ($cm.year^{-1}$)*	Wood classes and uses**
Pometia coriacea	0.20-2.50	Commercial group I, heavy, strong class II-III, durable class III-IV, veneer raw material, light construction, carving, flooring material, furniture, plywood, fruit price ± Rp. 25000-40000 / kg.
Pimelodendron amboinicum	0.30-2.20	Commercial I, heavy, soft, strong class III, durable class V, veneer material, plywood, furniture, etc.
Lepiniopsis ternatensis	0.40-2.70	Mixed forest group, heavy, soft, strong class III, durable class V, veneer raw material, furniture, sports equipment, musical instruments, painting tools, matches, molding, traditional boats, household appliances.
Palaquium amboinense	0.50-1.50	Commercial I, strong class II-III, durable class IV, veneer raw material, light construction, flooring, household appliances, wrapping boxes, plywood.
Spathiostemon javensis	0.30-0.90	Mixed forest group, heavy, strong class II, durability class V, traditionally used as house pillars and bridges.
Streblus elongatus	0.2-0.72	Mixed forest group, heavy, strong and durable, as the building material, furniture and household appliances, paddles, bridges, suitable for uses in salt water.
Sterculia macrophylla	0.58-0.98	Mixed forest group, building material, furniture, household appliances, as the medicinal plant, etc.
Prunus costata	0.40-0.82	Mixed forest group, building material, plywood, medicinal plant species, natural color source, shade tree.
Horsfieldia irya	0.50-1.30	Mixed forest group, building material, plywood, household appliances, shade plant, traditional toxic for fish, traditional boats.
Horsfieldia laevigata	0.50-2.40	Mixed forest group, building material, furniture and household appliances, traditional boats.
Geijera salicifolia	0.30-0.72	Mixed forest group, building material, furniture, contains anti-bacterial aromatic oil.
Dysoxylum mollissimum	0.30-1.60	Mixed forest group, building material, furniture, has been cultivated in forest plantations and community farms.
Pertusadina multifolia	0.15-0.23	Commercial I, Beauty II, heavy, very hard, as hence pillars, household appliance holders.
Haplolobus celebicus	0.40-0.76	Mixed forest group, strong class V, durable class III-IV, building material, furniture, household appliances, plywood, veneer.
Haplolobus lanceolatus	0.50-0.82	Mixed forest group, strong class V, durable class III-IV, veneer material, plywood, light construction, household appliances and furniture.
Intsia bijuga	0.00-0.76	Commercial I, heavy, strong class I-II, durable class II-III, building material, bridges, furniture, household appliances, ship, traditional boats, veneer, plywood.

Note: *Primary Data 2018. **Ministry of Agriculture of The Republic of Indonesia (1976), Forestry Service of Irian Jaya Province (1976), Sosef et al. (1998), Wong et al. (2002), Ishiguri et al. (2016), Sadgrove et al. (2014), Lemmens et al. (1995), Na Nakorn et al. (2016), Tamalene and Almudhar (2017), Normasiwi (2015), Efendi et al. (2016), Yarnvudhi et al. (2016), Martawijaya et al. (1989), Djarwanto et al. (2017)

Based on adaptation ability, the MATS with high association level were grouped in ESG I as the potential main shade trees while the species in ESG II were used as the alternative and complementary shade trees (Table 4). The main shade trees were the tree species planted with the main purpose of providing protection for the regeneration of merbau trees from direct sunlight exposure. The species of Euphorbiaceae dominated the main shad tree because it is the second largest family in GMNTPM after Moraceae, and has more than 12 species.

Meanwhile, the alternative and complementary shade trees were needed to improve soil fertility and engineered microclimate conditions. The alternative and complementary shade tree species were dominated by Myristicaceae and Burseraceae. In GMNTPM, it is known that there are more than eight species of Myristicaceae and more than four species of Burseraceae. Both families have fruit characteristics that support their spread and germination.

The economic potential of shade tree species can be increased through the application of timber processing technology and timber legality. Timber legality is important because the desire to pay people for certain forest products is also influenced by legality factors (Cai and Aguilar 2013; Holopainen et al. 2017).

Guides for the shade tree species selection

The construction of merbau plantations in Papua would be carried out in various microhabitat conditions with different physical soil properties. Therefore, the shade tree species with adaptability was required that was suitable for the merbau plantation environment later. To find out the ability of adaptation from the shade tree species in other regions in Papua, a literature study was conducted to complement the results of this research. Furthermore, the habitat of potential tree species were correlated to the soil properties of merbau habitat in Papua in order to formulate the scenario of the nature of merbau forest soil. The aim was to assist the selection of shade tree species that fit the physical properties of the planned merbau plantations.

Table 4. The potential species as the shade trees for merbau plantations in Papua

Species	Family
Main shade trees (ESG I)	
Pometia coriacea	Sapindaceae
Pimelodendron amboinicum	Euphorbiaceae
Palaquium amboinense	Sapotaceae
Spathiostemon javensis	Euphorbiaceae
Lepiniopsis ternatensis	Apocynaceae
Alternative and complementary shade trees (ESG II)	
Streblus elongatus	Moraceae
Sterculia macrophylla	Malvaceae
Haplolobus celebicus	Burseraceae
Haplolobus lanceolatus	Burseraceae
Pertusadina multifolia	Rubiaceae
Dysoxylum mollissimum	Meliaceae
Horsfieldia irya	Myristicaceae
Haplolobus laevigata	Myristicaceae
Prunus costata	Rosaceae
Geijera salicifolia	Rutaceae

Table 5. Description of the habitats of the potential shade trees species for merbau plantations

Species	Habitat
Pometia coriacea	Primary and secondary forests, clay, sandy and rocky soil, acidic-basic pH, 0-840 m asl., flat-steep slope, warm-hot weather, far from or near coasts.
Spathiostemon javensis	Primary forest, sandy, clay and rocky soil with no inundated water, flat-very wavy slope, secondary forest after logging, primary forest, 0-200 m above sea level, far from and near coasts.
Lepiniopsis ternatensis	Primary and secondary forests, sandy, clay and rocky soil with no inundated water, 0-350 m asl., flat-very wavy slope, far from and near beach.
Palaquium amboinense	Primary and secondary forests, loam sandy soil, sandy, sediment, rocky soil, soil with inundated water, flat-steep slope, 0-170 m asl.
Pimelodendron amboinicum	Primary and secondary forests, soil with no inundated water, flat-steep slope, 0-177 m asl.
Streblus elongatus	Primary and secondary forests, sandy soil, rocky and thick clays, 0-233 m asl., acidic-basic pH.
Prunus costata	Primary and secondary forests, sandy clay soil, rocky soil, acidic-basic pH, 0-170 m asl.
Dysoxylum mollissimum	Primary and secondary forests, sandy rocky clay soil, 0-1000 m asl., acidic-basic soils.
Haplolobus celebicus	Primary and secondary forests, sandy rocky clay soil, 0-400 m asl., acidic-basic soils.
Haplolobus lanceolatus	Primary and secondary forests, sandy rocky clay soil, 30-1000 m asl., acidic-basic pH.
Pertusadina multifolia	Primary forest, sandy rocky soil, acidic-basic pH, 0-400 m asl.
Geijera salicifolia	Primary forest, coastal forest, sandy rocky soil, acidic-basic pH, 0-170 m asl.
Horsfieldia irya	Primary forest, coastal forest, sandy rocky clay soil, acidic-basic pH, 0-160 m asl.
Horsfieldia laevigata	Primary forest, coastal forest, sandy rocky clay soil, acidic-basic pH, 0-160 m asl.
Sterculia macrophylla	Primary forest and secondary forests, sandy rocky clay soil, coastal forest, acidic-basic pH, 0-170 m asl.

Note: Lekitoo et al. (2008), Forestry Service of Irian Jaya Province (1976), Kuswandi et al. (2015), Murdjoko et al. (2016), Ministry of Agriculture of The Republic of Indonesia (1976), Normasiwi (2015), Chua et al. (2013), Khairil et al. (2014), Sarah et al. (2015), Triantoro et al. (2008), Slamet (2016), Siahaan and Sumadi (2015), Heriyanto and Bismark (2014)

Table 6. Choices of the potential shade tree species based on the scenario of merbau plantation soil conditions

Scenario of merbau plantation soil conditions	Choices of the shade trees	
	Main shade trees species (ESG I)	Alternative and complementary shade trees species (ESG II)
Relatively dry, rocky soil, quite close to the coasts	*Palaquium amboinense, Pometia coriacea, Lepiniopsis ternatensis, Spathiostemon javensis,*	*Geijera salicifolia, Dysoxylum mollissimum, Pertusadina multifolia*
Relatively dry, sandy soil, quite close to the coasts	*Palaquium amboinense, Pometia coriacea, Lepiniopsis ternatensis, Spathiostemon javensis*	*Dysoxylum mollissimum, Adina multifolia, Horsfieldia laevigata, Horfieldia irya, Prunus costata Geijera salicifolia*
Relatively humid, thick clay and sandy soil, quite far from the coasts	*Pometia coriacea, Lepiniopsis ternatensis, Pimelodendron amboinicum, Palaquium amboinense*	*Dysoxylum mollissimum, Horsfieldia laevigata, Horfieldia irya, Streblus elongatus, Prunus costata Sterculia macrophylla*
Relatively humid, thick clay soil, quite far from the coasts	*Pometia coriacea, Pimelodendron amboinicum, Palaquium amboinense*	*Haplolobus celebicus, Haplolobus lanceolatus, Streblus elongates, Prunus costata*

The data on soil physical properties of merbau habitats were colleted in Mappi Regency (Forestry Service of Papua Province 2010a) and Kaimana Regency (Reyaan 2013) which represented the Southern Papua bioregion, as well as in Mamberamo Raya Regency (Forestry Service of Papua Province 2010b) and the Padaido Biak islands (Sumaryono 2001) that represented the North Papua bioregion, also in Keerom Regency representing the East Papua bioregion (Forestry Service of Papua Province 2008), in GMNTPM (Sadono et al. 2014) to represent the West Papua bioregion.

The adaptability of the potential shade trees in a variety of physical properties of the soils (Table 5), the condition of the forests and the distance from which it grows from the coastlines. All potential shade trees have good adaptation to secondary and primary forests. This fact is an indicator that if merbau plantations are built on the forest after logging or critical lands, then these species can grow well to support merbau growth. The adaptability is due to a good fitness level because all the species are native. According to Savolainen et al. (2007), local species are those that show a higher level of fitness in local habitats and lower fitness in places far from their local habitat.

The position of either the main or complementary shade species of each merbau forest habitat can change if conditions permit. This is because some species may have a broader tolerance for specific environmental conditions such as the physical properties of the soil. Also, generally some forest plant populations will grow better in planted conditions than in native habitats, if there are eco-physiological changes such as avoiding them from competition (Mueller-Dombois and Ellenberg 1974). Examples of such species as *Pometia coriacea, Pimelodendron amboinicum, Palaquium amboinense, Lepiniopsis ternatensis*, *Dysoxylum* spp. and *Spathiostemon javensis* had good performance in the Arboretum at the University of Papua in Anggori Village, Manokwari. Other species such as *Palaquium* spp., *Intsia* spp., *Araucaria* sp., *Podocarpus* sp., *Pericopsis* sp., *Pometia* spp., *Callophyllum* sp., and *Vatica* sp. had good growth after 30 years of planting in the Agresi Research Forest of Manokwari (Hutapea et al. 2017). In Bengkulu, *Dysoxylum mollissimum* grown in plantations also had good growth with an average diameter of 18 cm (Ishiguri et al. 2016).

Guides for the shade tree selection in Table 6 are not fixed but as the initial guides for species selection. Thus, in order to obtain maximum growth results of merbau trees and the potential shade trees, appropriate silvicultural treatments are necessary, for instance arranging spaces between merbau trees as well as between merbau trees and the shade trees, pruning and thinning, and other silvicultural treatments so as to increase the growth of trees that has been planted.

The shade trees have the potential to support the growth of merbau rejuvenation in plantations because of better adaptation to the local environment. However, the 15 tree species recommended are only on the basis of ecological species group similarity perspective, growth rate and potential economic value. Therefore it is necessary to conduct further studies to find out other aspects related to the development of merbau plantations in Papua, such as pests and diseases, allelopathy, the content of organic ingredients, phenology, etc.

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