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ABSTRACTS

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UDC/ODC 630*5

Sandhi Imam Maulana

ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVE-GROUND BIOMASS IN PAPUA TROPICAL FOREST

(BERBAGAI PERSAMAAN ALLOMETRIK UNTUK PENDUGAAN BIOMASSA ATAS TANAH DI HUTAN TROPIS PAPUA)

Persamaan-persamaan allometrik sangat berguna untuk pendugaan biomassa dan stok karbon hutan. Namun, hingga saat ini, persamaan allometrik untuk jenis-jenis komersial di hutan tropis Papua masih sangat terbatas. Oleh karena itu, penelitian ini bertujuan untuk menyusun berbagai persamaan allometrik berdasarkan jenis-jenis komersial di Papua, meliputi genera Intsia, Pometia, Palaquium dan Vatica. Selain itu, satu persamaan juga dibangun khusus untuk mewakili kombinasi dari genera tersebut. Pohon contoh yang digunakan dalam penelitian ini berjumlah 49 dengan selang diameter setinggi dada (1,3 m) antara 5 hingga 40 cm. Metode pengambilan contoh menggunakan pendekatan destruktif dengan diameter setinggi dada (diameter at breast height/DBH) dan berat jenis (wood density/WD) digunakan sebagai penduga untuk total biomassa atas tanah (total above-ground biomass/TAGB). Perbandingan dan evaluasi model dilaksanakan berdasarkan nilai F-tabel, R-sq, R-sq (adj) dan simpangan rata-rata. Sedangkan untuk memenuhi asumsi penyusunan regresi, maka dilaksanakan uji multicollinearity untuk tiap model persamaan dengan lebih dari satu penduga dan uji normalitas distribusi residual (normal distribution of residuals). Berdasarkan indikator tersebut model yang paling sesuai untuk genera Intsia, Pometia, Palaquium dan Vatica secara berurutan adalah Log(TAGB) = -0,76 + 2,51Log(DBH), Log(TAGB) = -0,84 + 2,57Log(DBH), Log(TAGB) = -1,52 + 2,96Log(DBH), and Log(TAGB) = -0,09 + 2,08Log(DBH). Sementara itu, ditemukan bahwa penggunaan tinggi bebas cabang (commercial bole height/CBH) tidak mengindikasikan adanya peningkatan keterandalan model. Dari perbandingan antara persamaan allometrik untuk campuran jenis-jenis komersial sebagai hasil penelitian ini, yaitu Log(TAGB) = 0,205 + 2,08Log(DBH) + 1,75Log(WD), R-sq: 97,00%, R-sq (adj): 96,90%, F-statistics 750,67, average deviation: 3,50%, dengan berbagai persamaan allometrik yang telah dipublikasikan sebelumnya, didapatkan bahwa hasil pendugaan dari persamaan dalam penelitian ini lebih mendekati hasil perhitungan nyata, dan oleh sebab itu, suatu persamaan yang spesifik terhadap lokasi seharusnya lebih dipertimbangkan untuk mendapatkan pendugaan biomassa yang lebih baik.

Kata kunci: Alometrik, biomassa, berat jenis, Papua, hutan tropis

UDC/ODC 630*5

Nunung Puji Nugroho

RELATIONSHIP BETWEEN TOTAL TREE HEIGHT AND DIAMETER AT BREAST HEIGHT FOR TROPICAL PEAT SWAMP FOREST TREE SPECIES IN ROKAN HILIR DISTRICT, RIAU PROVINCE

(HUBUNGAN ANTARA TINGGI POHON TOTAL DAN DIAMETER SETINGGI DADA UNTUK JENIS-JENIS POHON HUTAN RAWA GAMBUT DI KABUPATEN ROKAN HILIR, PROPINSI RIAU)

Informasi tinggi pohon total (H) yang dapat dipercaya adalah sangat penting dalam pengelolaan sumberdaya hutan dan kajian-kajian ekologi hutan, termasuk dalam penaksiran biomassa hutan. Penambahan peubah H dapat meningkatkan performa dari persamaan alometrik biomassa dengan mengurangi rata-rata penyimpangan secara nyata. Namun demikian, pengukuran H adalah rumit, kurang akurat, memakan waktu, dan mahal. Jadi, H hanya diukur untuk pohon-pohon contoh di dalam plot, sedangkan diameter setinggi dada (D) umumnya diukur untuk setiap pohon selama kegiatan inventarisasi hutan. Informasi H yang hilang/tidak lengkap tersebut biasanya diduga berdasarkan suatu hubungan alometrik antara H dan D yang dibangun dari pohon-pohon contoh. Meskipun banyak kajian tentang pemodelan hubungan antara H dan D untuk hutan boreal dan untuk hutan jenis tunggal/tanaman, sedikit kajian yang fokus pada hutan tropis. Lebih lanjut lagi, hubungan tersebut untuk jenis-jenis pohon di hutan rawa gambut, dan terutama di Indonesia, belum terpublikasi secara luas. Jadi, tujuan dari kajian ini adalah untuk mengembangkan tapak spesifik model H-D untuk hutan rawa gambut dengan menggunakan fungsi regresi linier dan non-linier. Hasil dari kajian ini menunjukkan bahwa performa model-model non-linier lebih baik daripada yang linier berdasarkan parameter statistik dan kriteria biologis. Fungsi logistik yang dimodifikasi (Model 7) direkomendasikan untuk menduga H di wilayah kajian karena model ini mempunyai performa yang sebanding dengan fungsi eksponensial (Model 6) dan melalui titik diameter dan tinggi dengan nilai 0 cm dan 1,3 m. Namun demikian, kelima model non-linier tersebut mempunyai performa yang sebanding bagusnya dengan perbedaan yang tidak berarti. Perbaikan lebih lanjut dibutuhkan untuk meningkatkan keakurasian, kemampuan prediksi dan penerapan geografis dari model yang dikembangkan dengan mengelompokkan jenis-jenis pohonnya, menambahkan peubah yang mencirikan tegakan dan (atau) dengan menggunakan teknik-teknik lanjut model efek campur. Selain itu, validasi model seharusnya dilakukan sebelum penerapan model yang bersangkutan dengan mengumpulkan suatu dataset baru dari tegakan hutan yang sedang dikaji.

Kata kunci: Tapak-spesifik, model tinggi-diameter, fungsi regresi linier dan non-linier, hutan rawa gambut, Indonesia

UDC/ODC 630*892.52

Saefudin, Gunawan Pasaribu, Sofnie and Efrida Basri

THE EFFECT OF SAPPAN WOOD (*Caesalpinia sappan* L.) EXTRACT ON BLOOD GLUCOSE LEVEL IN WHITE RATS

(PENGARUH EKSTRAK KAYU SECANG (*Caesalpinia sappan* L.) PADA KADAR GULA DARAH TIKUS PUTIH)

Kayu Sappan atau kayu secang (*Caesalpinia sappan* L.) dilaporkan memiliki banyak manfaat sebagai tanaman obat, misalnya untuk antioksidan alami, meredakan muntah darah, dan bahan-bahan campuran untuk obat malaria. Penelitian ini bertujuan untuk mengetahui pengaruh ekstrak etanol dari kayu sappan pada kadar glukosa darah tikus putih. Tingkat glukosa darah pada tikus dilakukan dengan menggunakan metode toleransi glukosa. Ini diukur dengan Refloluxs (Accutrend GC) dengan kloropropamida 50 mg/200 g BB (berat badan) sebagai kontrol positif. Ekstrak etanol yang digunakan dalam berbagai konsentrasi 10, 20, 30, 40 dan 50 mg/200 g BB per-oral dan diamati setiap satu jam dan dimulai satu jam sebelum sampai 7 jam setelah ekstrak diberikan. Pemberian ekstrak 30 mg / kg BB tidak berbeda nyata dengan kontrol positip, sedang pemberian ekstrak 50 mg/200g BW menurunkan kadar glukosa darah (93 mg/dl) dibandingkan dengan kontrol positif.

Kata kunci: Kayu secang, ekstrak etanol, kadar glukosa darah, tikus, obat

UDC/ODC 630*22

Relawan Kuswandi

THE EFFECT OF SILVICULTURAL TREATMENT ON STAND GROWTH OF LOGGED-OVER FOREST IN SOUTH PAPUA

(PENGARUH PENERAPAN PERLAKUAN SILVIKULTUR PADA HUTAN BEKAS TEBANGAN DI PAPUA SELATAN)

Kondisi tegakan hutan dapat digunakan sebagai salah satu indikator dalam menentukan adanya kemungkinan untuk penentuan penebangan pada hutan bekas tebangan. Hal ini dapat dilakukan dengan menganalisis kondisi tegakan tersebut dengan menggunakan data dari pengukuran periodik yang dilakukan pada petak ukur permanen (PUP). Pendirian PUP dilakukan oleh pemegang IUPHHK dengan tujuan untuk monitoring pertumbuhan tegakan setelah penebangan. Penelitian ini dilakukan dengan menggunakan PUP yang dilakukan perlakuan penjarangan dan PUP yang tidak ada perlakuan silvikultur (control). Hasil penelitian menunjukkan bahwa setelah penebangan, terdapat perbedaan struktur tegakan pada kedua tipe PUP tersebut dalam hal in-growth, up-growth dan mortality. Selanjutnya pada pertumbuhan tegakan pada PUP tanpa perlakuan lebih tinggi yaitu 0,60 cm per tahun, sedangkan untuk tegakan pada PUP perlakuan adalah 0,55 cm per tahun.

Kata kunci: Struktur tegakan, hutan bekas tebangan, hutan alam, riap

UDC/ODC 630*892.72

Budi Leksono, Rina Laksmi Hendrati, Eritrina Windyarini, Trimaria Hasnah

VARIATION OF BIOFUEL POTENTIAL OF TWELVE *Calophyllum inophyllum* POPULATIONS IN INDONESIA

(VARIASI POTENSI BIOFUEL DARI DUA BELAS POPULASI *Calophyllum inophyllum* DI INDONESIA)

Krisis energi mendorong penduduk dunia untuk mengalihkan sumber energinya ke energi terbarukan (biofuel) yang lebih ramah lingkungan. Nyamplung (*Calophyllum inophyllum*) sebagai salah satu jenis tanaman hutan mempunyai potensi sebagai bahan baku biofuel dari bijinya dan dapat berproduksi sampai dengan umur 50 tahun. Secara teknis pemanfaatan biji nyamplung sebagai biofuel tidak menjadi masalah dan sudah mulai dikembangkan dalam skala industri oleh Koperasi Jarak Lestari di Cilacap (Jawa Tengah) dan melalui program Desa Mandiri Energi (DME) berbasis nyamplung di Banyuwangi (Jawa Timur), Purworejo dan Kebumen (Jawa Tengah), Ujung Kulon (Banten), dan Selayar (Sulawesi Selatan). Namun demikian, ketersediaan dan kualitas bahan baku dari biji nyamplung menjadi kendala utama karena belum tersedia informasi produktivitas minyak yang optimal. Tulisan ini menyajikan variasi potensi biofuel nyamplung dari 12 (dua belas) populasi nyamplung di Indonesia (6 populasi di Jawa dan 6 populasi di luar Jawa) untuk membangun sumber benih unggul nyamplung. Rendemen minyak dihasilkan dengan menggunakan kombinasi alat Vertical Hot Press (VHP) dan Screw Press Expeller (SPE) dilanjutkan dengan proses degumming untuk menghasilkan refined oil dan proses esterifikasi-transesterifikasi untuk menghasilkan biodiesel. Hasil penelitian menunjukkan terdapat variasi yang cukup tinggi diantara populasi nyamplung di Indonesia terhadap rendemen biofuel. Persentase rendemen minyak bervariasi antara 37-48,5% dengan VHP dan 50-58% dengan SPE untuk crude oil, 36-48% (VHP) dan 40-53% (SPE) refined oil, dan 17-33% (SPE) untuk biodiesel. Variasi tertinggi ditunjukkan pada rendemen biofuel setelah degumming karena biji nyamplung mengandung getah yang cukup tinggi. Informasi rendemen biofuel dan analisa DNA serta kondisi lingkungan dari setiap populasi menjadi faktor penting untuk pembangunan sumber benih unggul.

Kata kunci: Biofuel, crude oil, refined oil, nyamplung (*Calophyllum inophyllum*), variasi genetik

UDC/ODC 630*235.42

Ishak Yassir and Arbainsyah

DIVERSITY OF PLANT COMMUNITIES IN SECONDARY SUCCESSION OF IMPERATA GRASSLANDS IN SAMBOJA LESTARI, EAST KALIMANTAN, INDONESIA

(KEANEKARAGAMAN KOMUNITAS TUMBUHAN DALAM SUKSESI SUKENDER LAHAN ALANG-ALANG DI SAMBOJA LESTARI, KALIMANTAN TIMUR, INDONESIA)

Regenerasi alami pada lahan alang-alang menjadi semakin penting, baik untuk menciptakan hutan sekunder baru dan memulihkan keanekaragaman hayatinya. Kami mempelajari keanekaragaman komunitas tumbuhan dalam suksesi sekunder di lahan alang-alang menggunakan 45 subplot dari 9 transek linier (10 mx 100 m). Data yang dikumpulkan dan diidentifikasi dari semua jenis yang ditemukan dengan ukuran diameter setinggi dada lebih dari 10 cm, kemudian dihitung dan dianalisis Indek Nilai Penting (INP) baik untuk tingkat pohon, sapling dan anakan, dan sampel tanah yang diambil kemudian dianalisis. Hasil penelitian menunjukkan bahwa selama proses regenerasi setelah lebih dari 10 tahun, 65 famili ditemukan dimana terdiri dari 164 jenis, yang didominasi oleh *Vernonia arborea* Buch.-Ham, *Vitex pinnata* L., *Macaranga gigantea* (Reichb.f. & Zoll.) Muell.Arg., *Symplocos crassipes* CB Clarke, *Artocarpus odoratissimus* Miq., dan *Bridelia glauca* Blume. Pengaruh regenerasi dari lahan alang-alang menjadi hutan sekunder terhadap kondisi tanah terkuat di horizon-A, dimana terjadi peningakatan Karbon, Nitrogen dan pH. Hasil penelitian ini menunjukkan bahwa lahan alang-alang tampak permanen karena mengalami kebakaran yang berulang dan campur tangan manusia dan sejauh ini masih sedikit upaya yang telah dilakukan untuk melakukan merehabilitasi yang berkelanjutan. Jika dilindungi dari kebakaran dan gangguan lain seperti peladang berpindah, lahan alang-alang akan tumbuh dan berkembang menjadi hutan sekunder.

Kata kunci: Lahan alang-alang, Indek Nilai Penting, regenerasi, suksesi

ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVE-GROUND BIOMASS IN PAPUA TROPICAL FOREST

Sandhi Imam Maulana[1*]

Received : 15 June 2012, Accepted : 20 April 2014

ABSTRACT

Allometric equations can be used to estimate biomass and carbon stock of the forest. However, so far the allometric equations for commercial species in Papua tropical forests have not been appropriately developed. In this research, allometric equations are presented based on the genera of commercial species. Few equations have been developed for the commercial species of Intsia, Pometia, Palaquium and Vatica genera and an equation of a mix of these genera. The number of trees sampled in this research was 49, with diameters (1.30 m above-ground or above buttresses) ranging from 5 to 40 cm. Destructive sampling was used to collect the samples where Diameter at Breast Height (DBH) and Wood Density (WD) were used as predictors for dry weight of Total Above-Ground Biomass (TAGB). Model comparison and selection were based on the values of F-statistics, R-sq, R-sq (adj), and average deviation. Based on these statistical indicators, the most suitable model for Intsia, Pometia, Palaquium and Vatica genera respectively are Log(TAGB) = -0.76 + 2.51Log(DBH), Log(TAGB) = -0.84 + 2.57Log(DBH), Log(TAGB) = -1.52 + 2.96Log(DBH), and Log(TAGB) = -0.09 + 2.08Log(DBH). Additional explanatory variables such as Commercial Bole Height (CBH) do not really increase the indicators' goodness of fit for the equation. An alternative model to incorporate wood density should be considered for estimating the above-ground biomass for mixed genera. Comparing the presented mixed-genera equation; Log(TAGB) = 0.205 + 2.08Log(DBH) + 1.75Log(WD), R-sq: 97.0%, R-sq (adj): 96.9%, F-statistics 750.67, average deviation: 3.5%; to previously published data shows that this local species-specific equation differs substantially from previously published equations and this site-specific equation is considered to give a better estimation of biomass.

Keywords: Allometric, biomass, wood density, Papua, tropical forest

ABSTRAK

Persamaan-persamaan alometrik sangat berguna untuk pendugaan biomassa dan stok karbon hutan. Namun, hingga saat ini, persamaan alometrik untuk jenis-jenis komersial di hutan tropis Papua masih sangat terbatas. Oleh karena itu, penelitian ini bertujuan untuk menyusun berbagai persamaan allometrik berdasarkan jenis-jenis komersial di Papua, meliputi genus Intsia, Pometia, Palaquium dan Vatica. Selain itu, satu persamaan juga dibangun khusus untuk mewakili kombinasi dari genera tersebut. Pohon contoh yang digunakan dalam penelitian ini berjumlah 49 dengan selang diameter setinggi dada (1,3 m) antara 5 hingga 40 cm. Metode pengambilan contoh menggunakan pendekatan destruktif dengan diameter setinggi dada (diameter at breast height/DBH) dan berat jenis (wood density/WD) digunakan sebagai penduga untuk total biomassa atas tanah (total above ground biomass/TAGB). Perbandingan dan evaluasi model dilaksanakan berdasarkan nilai F-tabel, R-sq, R-sq (adj) dan simpangan rata-rata. Sedangkan untuk memenuhi asumsi penyusunan regresi, maka dilaksanakan uji multicollinearity untuk tiap model persamaan dengan lebih dari satu penduga dan uji normalitas distribusi residual (normal distribution of residuals). Berdasarkan indikator tersebut model yang paling sesuai untuk genera Intsia, Pometia, Palaquium dan Vatica secara berurutan

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adalah Log(TAGB) = -0,76 + 2,51Log(DBH), Log(TAGB) = -0,84 + 2,57Log(DBH), Log(TAGB) = -1,52 + 2,96Log(DBH), and Log(TAGB) = -0,09 + 2,08Log(DBH). Sementara itu, ditemukan bahwa penggunaan tinggi bebas cabang (commercial bole height/CBH) tidak mengindikasikan adanya peningkatan keterandalan model. Dari perbandingan antara persamaan alometrik untuk campuran jenis-jenis komersial sebagai hasil penelitian ini, yaitu Log(TAGB) = 0,205 + 2,08Log(DBH) + 1,75Log(WD), R-sq: 97,00%, R-sq (adj): 96,90%, F-statistics 750,67, average deviation: 3,50%, dengan berbagai persamaan alometrik yang telah dipublikasikan sebelumnya, didapatkan bahwa hasil pendugaan dari persamaan dalam penelitian ini lebih mendekati hasil perhitungan nyata, dan oleh sebab itu, suatu persamaan yang spesifik terhadap lokasi seharusnya lebih dipertimbangkan untuk mendapatkan pendugaan biomassa yang lebih baik.

Kata kunci: Alometrik, biomassa, berat jenis, Papua, hutan tropis

I. INTRODUCTION

Forest ecosystem is an important carbon sink and source and containing the majority of above-ground terrestrial organic carbon. Four main carbon pools in forest ecosystem are including tree biomass, necromass, under-storey and soil organic matters (Hairiah and Rahayu, 2007). The largest carbon stock comes from above-ground tree biomass, but this carbon pool was also the most vulnerable to deforestation and forest degradation. Therefore, the estimation of total above-ground biomass is an important step in quantifying carbon stock of tropical forest (Post et al., 1999; Brown and Masera, 2003; Pearson et al., 2005; IPCC, 2006; Hairiah and Rahayu, 2007).

Basically, the estimation of above-ground biomass can be conducted via two approaches, which are destructive and non-destructive (Samalca, 2007). Direct estimation of above-ground biomass through destructive approach is the most accurate approach, although this approach tends to be more costly, requires more man-power, and time, if compared to the non-destructive approach (Lu, 2006). Generally, destructive approach is used only as a tool in validating the result of the non-destructive approach that was using allometric equations (Clark et al., 2001; de Gier, 2003; Wang et al., 2003). These equations developed based on the correlations between diameter at breast height (DBH), or other tree variables, against its total above-ground biomass (Brown, 1997).

The implementation of species and site-specific allometric equations is strongly suggested, because trees from different site will grow with a different architecture, wood density and other life patterns (Ketterings et al., 2001). In order to achieve the highest level of accuracy, local species and site-specific allometric equations must be established (Samalca, 2007; Basuki et al., 2009). This research aims to produce species and site-specific allometric equations to estimate total above-ground biomass of four genera of commercial species in Papua.

II. MATERIAL AND METHOD

A. Site Description

This research was conducted at four different regencies in Papua and West Papua Province (Figure 1). The number of trees sampled in this research was 49, with diameters (1.30 m above ground or above buttresses) ranging from 5 to 40 cm, which consisted of four different genera as presented in Table 1.

B. Method

DBH was measured prior conducting the destructive sampling. Generally the DBH was measured at 1.30 m above-ground, but for trees with enlargement or buttresses, the diameter was measured at 30 cm above the main enlargement. After felling, the tree height was measured. Diameter was measured at 2 m intervals for the stems and big branches with the diameters of more than 15 cm. In addition, the stump height and its diameter were also measured. These measurements were used to estimate the volume and dry weight. The volume of each section was calculated using Smalian's formula as cited by de Gier (2003). The total volume is the sum of the volume of each section. Due to the difference in moisture content, the tree material was partitioned into leaves, twigs (diameter <3.2 cm), small branches (diameter 3.2–6.4 cm), large branches (diameter >6.4 cm) and stem (Ketterings et al., 2001).

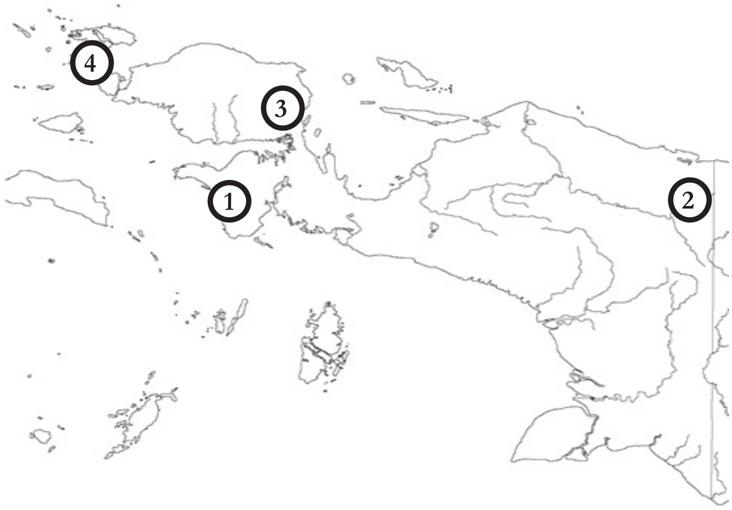

Figure 1. Research site map

Table 1. Details of number of trees taken per genus and location

Research site	Genera	Number of trees	Location	Coordinate	Site characteristics as taken from BPS Papua (2009) and BPS Papua Barat (2011)
1.	Intsia	13	Fak-fak	2^{0}25'0"- 4^{0}0'0" S 131^{0}30'0" - 138^{04}0'0" E	- 500 m above sea level - daily temperature: 24-31°C - average humidity: 84% - annual rainfall: 3,265 mm/year - soil type: carbosol and yellow-reddish podsolic
2.	Pometia	15	Keerom	140^{0}15'0"-141^{0}0'0" S 2^{0}37'0" - 4^{0}0'0" E	- 1000 m above sea level - daily temperature: 21.9-33°C - average humidity: 85% - annual rainfall: 4,151 mm/year - soil type: grey-brown and yellow-reddish podsolic
3.	Palaquium	13	Bintuni	1^{0}57'50"-3^{0}11'26" S 132^{0}44'59"-134^{0}14'49" E	- 500 m above sea level - daily temperature: 25-31°C - average humidity: 85% - annual rainfall: 3,008.9 mm/year - soil type: alluvial, gleysol and podsolic
4.	Vatica	8	Raja Ampat	0^{o}10' S - 0^{o}20' N 130^{o}0' W- 132^{o}0'55" E	- 500 m above sea level - daily temperature: 25-30°C - average humidity: 84% - annual rainfall: 3,836.4 mm/year - soil type: alluvial, organosol, grey podsolic and yellow-reddish podsolic

Afterwards, fresh weight from leaves, twigs, branches and stems with maximum diameters of 15 cm were measured directly in the field using hang-up balance of 50 kg capacity with an accuracy of 1%. Moreover, the smaller samples were weighed using a 1000 gr table scale with an accuracy of 0.5%. Three replications were taken for the samples from the partitioned trees and put into sealed plastic bags, and then brought to the laboratory to measure their moisture content. From that point, an analytical balance with maximum capacity of 500 gr and an accuracy of 0.001 gr was utilized to weigh those samples. Dry weights were obtained by drying the samples at 105°C temperature until the constant value was obtained (Stewart et al., 1992; Ketterings et al., 2001).

In order to measure the wood density at the laboratory, samples were taken from the lower and upper parts of the main trunk sections with 2 meters interval for each section. To include the inner and outer parts of the trunks with

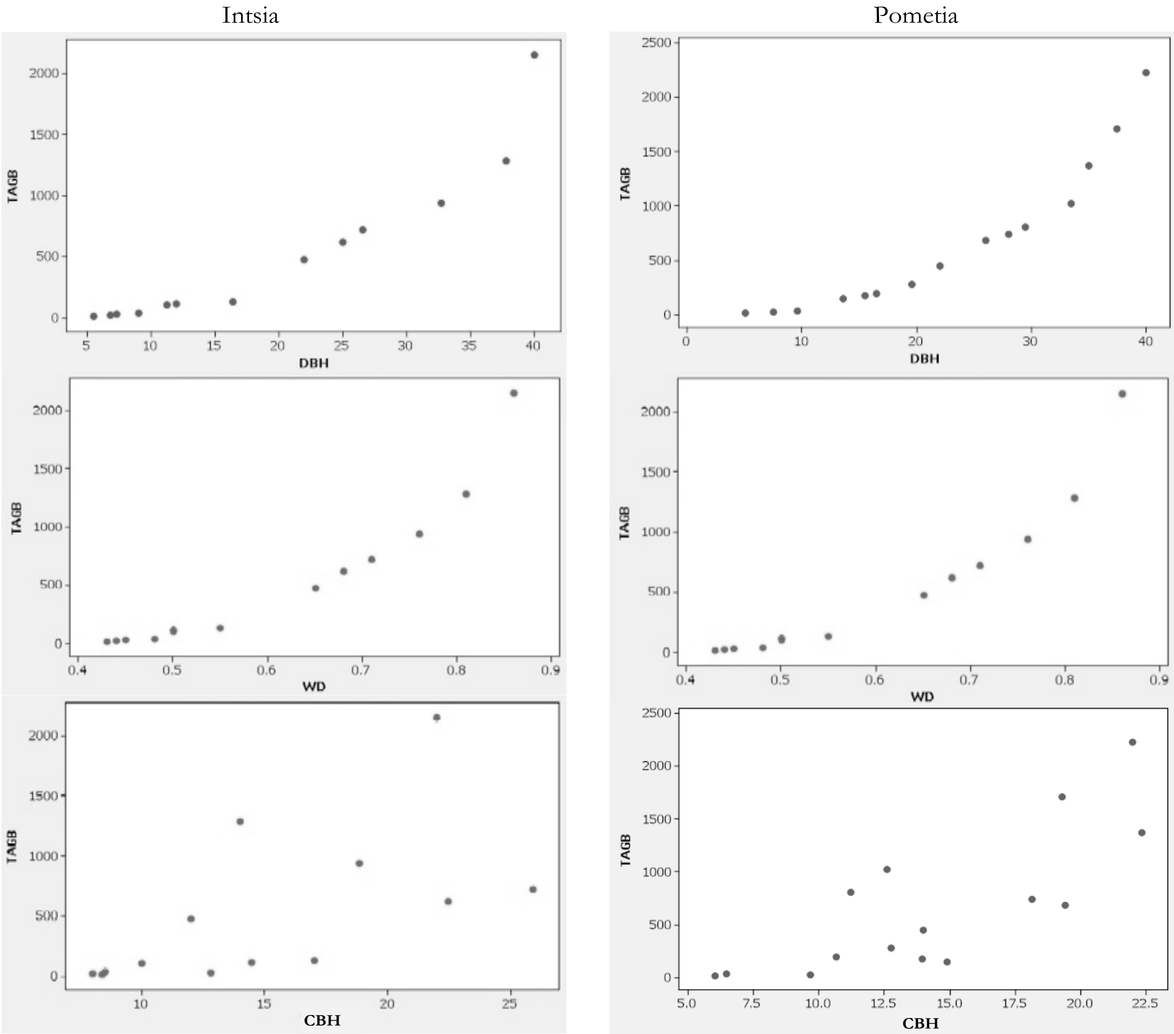

Figure 2. Scatter plots of Intsia and Pometia

Remarks :
TAGB: Total Above-Ground Biomass (kg/tree)
DBH: Diameter at Breast Height (cm)
WD: Wood Density (gr/cm^3)
CBH: Commercial Bole Height (m)

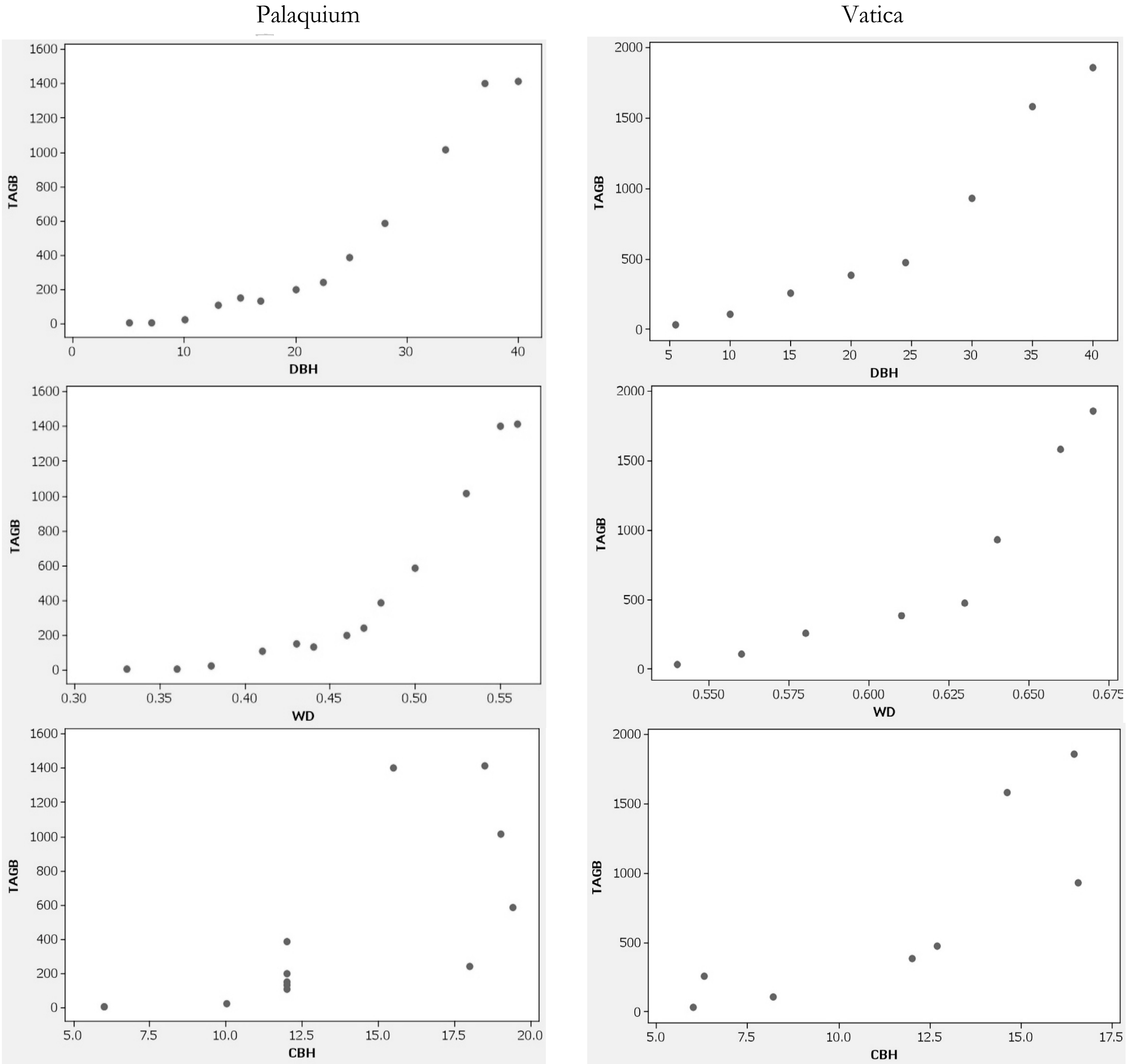

Figure 3. Scatter plot of Palaqium and Vatica

Remarks :
TAGB: Total Above-Ground Biomass (kg/tree)
DBH: Diameter at Breast Height (cm)
WD: Wood Density (gr/cm^3)
CBH: Commercial Bole Height (m)

their barks, the samples were taken as a pie shape or cylinder (Nelson et al., 1999). Water replacement method was used in measuring the wood density. The samples were saturated at first to prevent size contraction during volume measurement. This was conducted through 48 hours rehydration. Each sample's volume was obtained from the displaced water volume when submerged. Finally, the wood density was equal to the oven dry weight divided by saturated volume.

The dry weight of the stumps, stems, and branches with the diameter of >15 cm was calculated by multiplying the fresh volume of each section by wood density. For the other partitioned trees, the dry weight was calculated through fresh weight multiplied by dry weight divide by fresh weight ratio of the corresponding samples. The total dry weight of a tree is the sum of the dry weight of the stump, stem, branches, twigs, and leaves (Stewart et al., 1992).

Based on the data collected, several equations were developed. Firstly, the equations were developed for four individual genera (Intsia, Pometia, Palaquium and Vatica). Secondly, these four genera were mixed to develop an equation for commercial species. Before the establishment of these allometric equations, scatter plots were used to see whether the relationship between independent and dependent variables was linear. Furthermore, several allometric relationships between independent and dependent variables were tested. The independent variables included Diameter at Breast Height (DBH), Commercial Bole Height (CBH) and Wood Density (WD), whereas the dependent variable was the dry weight of the Total Above-Ground Biomass (TAGB). Model comparison and selection was analyzed using the value of standard error of the coefficient, F statistic, R-sq, R-sq (adj) based on Minitab 14.0 software. The chosen model would be the one with not only the highest value for each criterion, but also one that have the lowest value of average deviation among others, as suggested by Basuki et al. (2009). Besides, in order to fulfill assumptions in regression establishment, two tests were conducted, namely Variance Influential Factors (VIF) for multi-collinearity test, which aimed at equations with more than one predictor, and normal distribution of residual test. Meanwhile, in this research allometric equations were established based on logarithmic model taken from Basuki et al. (2009) and quadratic model, as follow:

a.) $\text{Log(TAGB)} = c + \alpha \text{ Log(DBH)}$
b.) $\text{Log(TAGB)} = c + \alpha \text{ Log(WD)}$
c.) $\text{Log(TAGB)} = c + \alpha \text{ Log(DBH)} + \beta \text{ Log(WD)}$
d.) $\text{TAGB} = c + \alpha\text{(DBH)} + \beta\text{(DBH)2}$
e.) $\text{TAGB} = c + \alpha\text{(WD)} + \beta\text{(WD)2}$

III. RESULT AND DISCUSSION

A. Allometric Equations

The selection of independent variables as predictors in allometric equation were chosen based on the correlation patterns between each independent variable (DBH, CBH, and WD) against its dependent variable (TAGB). Figure 2 and 3 shows that the independent variable Commercial Bole Height (CBH) is forming a random correlation to total above-ground biomass. As a result, CBH cannot be used as an independent variable in the allometric equation because it will not increase the goodness of fit for the equations. Besides that, Figure 2 and 3 also show that DBH and WD are forming an exponential growth pattern to total above-ground biomass. This pattern shows that all of sampled trees were still in the growing stage.

Based on those exponential growth patterns as shown in Figure 2 and 3, there are two

Table 2. Result of measuring wood density and the published data

Species Grouping (Genera)	Number of wood density sample (n)	Range (gr/cm^3)		Average (gr/cm^3)	Standard deviation	PROSEA* (gr/cm^3)
		min	max			
Intsia	92	0.43	0.86	0.6	0.15	0.5-1.04
Pometia	98	0.37	0.75	0.58	0.12	0.39-0.77
Palaquium	86	0.33	0.56	0.45	0.07	0.45-0.51
Vatica	44	0.54	0.67	0.61	0.05	0.6-0.76

Remark: *published data

Table 3. Multi-collinearity test using VIF value

Species Grouping (Genera)	N	Equations	Coefficient		Multi-collinearity Test	
			Symbol	Values	Predictor	VIF
Intsia	13	$\text{Log TAGB} = c + \alpha \text{ Log DBH}$	c	-0.762	Log DBH	-
			α	2.51	-	
		$\text{Log TAGB} = c + \alpha \text{ Log WD}$	c	3.86	Log WD	-
			α	6.92	-	
		$TAGB = c + \alpha DBH + \beta DBH^2$	c	128.3	DBH	24.9
			α	-24.70	DBH^2	24.9
			β	1.678	-	
		$TAGB = c + \alpha WD + \beta WD^2$	c	3090	WD	140.1
			α	-12718	WD^2	140.1
			β	13244	-	
Pometia	15	$\text{Log TAGB} = c + \alpha \text{ Log DBH}$	c	-0.8406	Log DBH	-
			α	2.572	-	
		$\text{Log TAGB} = c + \alpha \text{ Log WD}$	c	4.267	Log WD	-
			α	7.214	-	
		$TAGB = c + \alpha DBH + \beta DBH^2$	c	232.5	DBH	23.5
			α	-40.46	DBH^2	23.5
			β	2.131	-	
		$TAGB = c + \alpha WD + \beta WD^2$	c	4632	WD	118.1
			α	-20620	WD^2	118.1
			β	22886	-	
Palaquium	13	$\text{Log TAGB} = c + \alpha \text{ Log DBH}$	c	-1.52	Log DBH	-
			α	2.96	-	
		$\text{Log TAGB} = c + \alpha \text{ Log WD}$	c	6.217	Log WD	-
			α	11.59	-	
		$TAGB = c + \alpha DBH + \beta DBH^2$	c	111.30	DBH	20.9
			α	24.13	DBH^2	20.9
			β	1.489	-	
		$TAGB = c + \alpha WD + \beta WD^2$	c	6618	WD	167.3
			α	35000	WD^2	167.3
			β	46043	-	
Vatica	8	$\text{Log TAGB} = c + \alpha \text{ Log DBH}$	c	-0.0975	Log DBH	-
			α	2.086	-	
		$\text{Log TAGB} = c + \alpha \text{ Log WD}$	c	6.368	Log WD	-
			α	17.67	-	
		$TAGB = c + \alpha DBH + \beta DBH^2$	c	130.90	DBH	22.4
			α	21.50	DBH^2	22.4
			β	1.658	-	
		$TAGB = c + \alpha WD + \beta WD^2$	c	51612	WD	1198.7
			α	182565	WD^2	1198.7
			β	161565	-	
Commercial Species (Mixed)	49	$\text{Log TAGB} = c + \alpha \text{ Log DBH}$	c	-0.881	Log DBH	-
			α	2.580	-	
		$\text{Log TAGB} = c + \alpha \text{ Log WD}$	c	4.065	Log WD	-
			α	6.455	-	
		$\text{Log TAGB} = c + \alpha \text{ Log DBH} + \beta \text{ Log WD}$	c	0.205	Log DBH	2.8
			α	2.08	Log WD	2.8
			β	1.75	-	
		$TAGB = c + \alpha DBH + \beta DBH^2$	c	152.49	DBH	22.9
			α	-28.764	DBH^2	22.9
			β	1.7689	-	
		$TAGB = c + \alpha WD + \beta WD^2$	c	-7	WD	67.1
			α	-1928	WD^2	67.1
			β	5070	-	-

methods for approaching the established equations in order to achieve highest level of accuracy, first by establishing an equation following quadratic model and second by following logarithmic model based on basic equation model as suggested by Basuki et al.

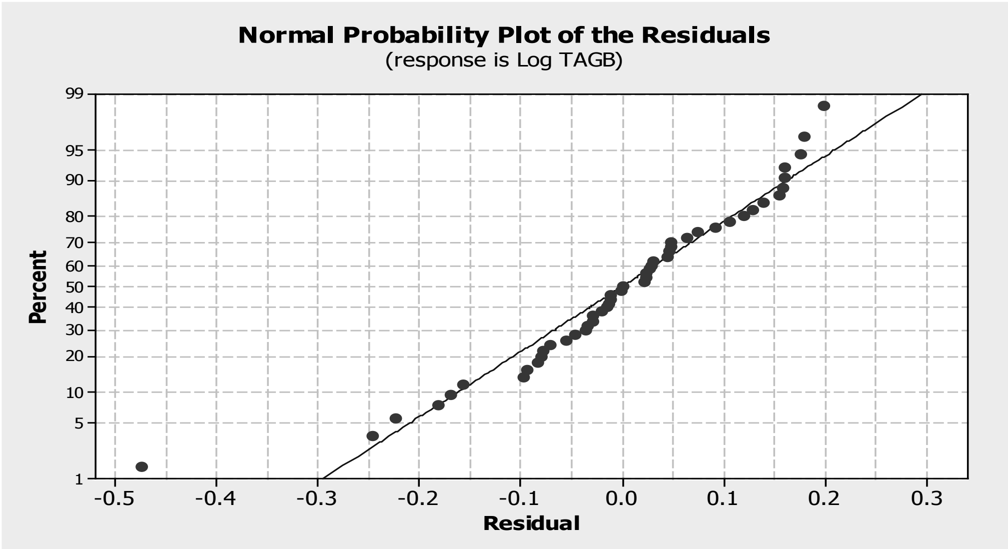

Figure 4. Normal distribution of residual graph for allometric model of mixed species

(2009). Similarly, Grant et al. (1997) and Stewart (1998) also declared that the exponential growth relationship can be explained through quadratic equations, and it will raise the accuracy level of the estimated values if converted to a regression which relies on logarithmic models.

It is possible that during the equations establishment process in this study, the differences in wood density among tree sections were the biggest source of errors. This source of error is in agreement with Basuki et al. (2009). Wood density differs among the tree sections; it tends to be higher at the breast height than at the top of the bole and also higher at the base of the tree stem than at the base of the living crown (Nogueira et al., 2005).

In this study, although the samples for wood density analyses were taken from the upper and lower part of each main trunk section with 2 m interval. These data were also used to estimate the weight of the big branches that were impossible to be weighed. This possibly caused an over-estimation of the weight for individual trees. Wood density data for all genera are presented in Table 2.

Before evaluating established allometric equations, multi-collinearity test was conducted on every equation that used more than one predictor, such as TAGB = c + α(DBH) + β(DBH)2; TAGB = c + α(WD) + β(WD)2; and Log(TAGB)= c + α Log(DBH) + β Log(WD). The result of this test is shown in Table 3. Based on this table, it is apparently clear that the utilization of DBH and DBH2 as predictors simultaneously in one equation produced a high value of Variance Influential Factors (VIF) that is more than 10. Similarly, the use of WD and WD2 together in one equation is also resulted in more than 10 points of VIF value. This finding implies that model TAGB = c + α(DBH) + β(DBH)2 and TAGB = c + α(WD) + β(WD)2 indicate the existence of multicollinearity due to high correlation among their predictors. As described by Fahrmeir et al. (2013), if VIF value goes beyond 10, it is highly likely that the regression predictors need to be concerned due to multi-collinearity that may become problematic in the prediction of the results of the model. In contrast, the use of Log DBH and Log WD simultaneously in Log(TAGB)= c + α Log(DBH) + β Log(WD) model, has only produced 2.8 points of VIF value. This means that although there is an indication of low degree of correlation among its predictors, the value of VIF is not enough to be overly concerned about (Fahrmeir et al.,

Table 4. Results of establishing allometric equations

Species Grouping (Genera)	N	Equations	Coefficient Symbol	Coefficient Values	Standard Error of the Coefficient	T-Stat	R^2 (%)	R^2 Adj (%)	F-Stat	Average Deviation (%)
Intsia	13	Log TAGB = c + α Log DBH	c	-0.762	0.1097	6.95	98.60	98.50	797.51	1.70
			α	2.51	0.0889	28.24				
		Log TAGB = c + α Log WD	c	3.86	0.1032	37.41	96.40	96.00	291.52	3.90
			α	6.92	0.4051	17.07				
		TAGB = c + α DBH + β DBH^2	c	128.3	167.1	0.77	94.90	93.90	93.03	27.65
			α	-24.70	18.84	1.31				
			β	1.678	0.4188	4.01				
		TAGB = c + α WD + β WD^2	c	3090	741.8	4.17	97.60	97.10	204.60	46.06
			α	-12718	2463	5.16				
			β	13244	1948	6.80				
Pometia	15	Log TAGB = c + α Log DBH	c	-0.8406	0.102	8.21	98.80	98.70	1090.5	1.56
			α	2.572	0.078	33.02				
		Log TAGB = c + α Log WD	c	4.267	0.066	64.43	98.50	98.40	839.64	1.92
			α	7.214	0.249	28.98				
		TAGB = c + α DBH + β DBH^2	c	232.5	123.5	1.88	97.80	97.40	267.56	40.72
			α	-40.46	12.44	3.25				
			β	2.131	0.269	7.90				
		TAGB = c + α WD + β WD^2	c	4632	771.7	6.00	97.40	97.00	223.77	43.92
			α	-20620	2840	7.26				
			β	22886	2526	9.06				
Palaquium	13	Log TAGB = c + α Log DBH	c	-1.52	0.1899	8.01	97.30	97.10	396.85	4.74
			α	2.96	0.1482	19.92				
		Log TAGB = c + α Log WD	c	6.217	0.2365	26.28	96.50	96.20	302.46	7.97
			α	11.59	0.6666	17.39				
		TAGB = c + α DBH + β DBH^2	c	111.30	85.08	1.31	98.30	97.90	284.40	33.92
			α	24.13	8.677	2.78				
			β	1.489	0.1887	7.89				
		TAGB = c + α WD + β WD^2	c	6618	855.6	7.73	97.40	97.00	284.23	37.17
			α	35000	3863	9.06				
			β	46043	4288	10.74				
Vatica	8	Log TAGB = c + α Log DBH	c	-0.0975	0.1143	0.85	99.00	98.80	569.13	0.69
			α	2.086	0.08742	23.86				
		Log TAGB = c + α Log WD	c	6.368	0.3444	18.49	95.40	94.60	124.31	0.86
			α	17.67	1.585	11.15				
		TAGB = c + α DBH + β DBH^2	c	130.90	161.1	0.81	98.20	97.40	133.08	7.64
			α	21.50	16.3	1.32				
			β	1.658	0.3507	4.73				
		TAGB = c + α WD + β WD^2	c	51612	12972	3.98	96.40	94.90	66.07	28.20
			α	182565	43019	4.24				
			β	161565	35504	4.55				
Commercial Species (Mixed)	49	Log TAGB = c + α Log DBH	c	-0.881	0.1101	8.00	95.10	94.90	903.08	8.23
			α	2.580	0.08584	30.05				
		Log TAGB = c + α Log WD	c	4.065	0.155	26.23	74.70	74.20	138.76	38.33
			α	6.455	0.548	11.78				
		Log TAGB= c + α Log DBH + β Log WD	c	0.205	0.2047	0.95	97.00	96.90	750.67	3.50
			α	2.08	2.0840	18.59				
			β	1.75	1.7491	5.53				
		TAGB = c + α DBH + β DBH^2	c	152.49	80.71	1.89	95.20	95.00	454.86	51.79
			α	-28.764	8.426	3.41				
			β	1.7689	0.1843	9.60				
		TAGB = c + α WD + β WD^2	c	-7	1006	0.01	64.30	62.80	41.47	38.97
			α	-1928	3578	0.54				
			β	5070	3083	1.64				

2013).

The results of establishing allometric equations and their evaluation are shown in Table 4. Based on Table 4, the most appropriate equation to estimate TAGB for each genus is Log(TAGB) = c + α Log(DBH), this model uses only a single predictor, the DBH, and produces a range of prediction values closer

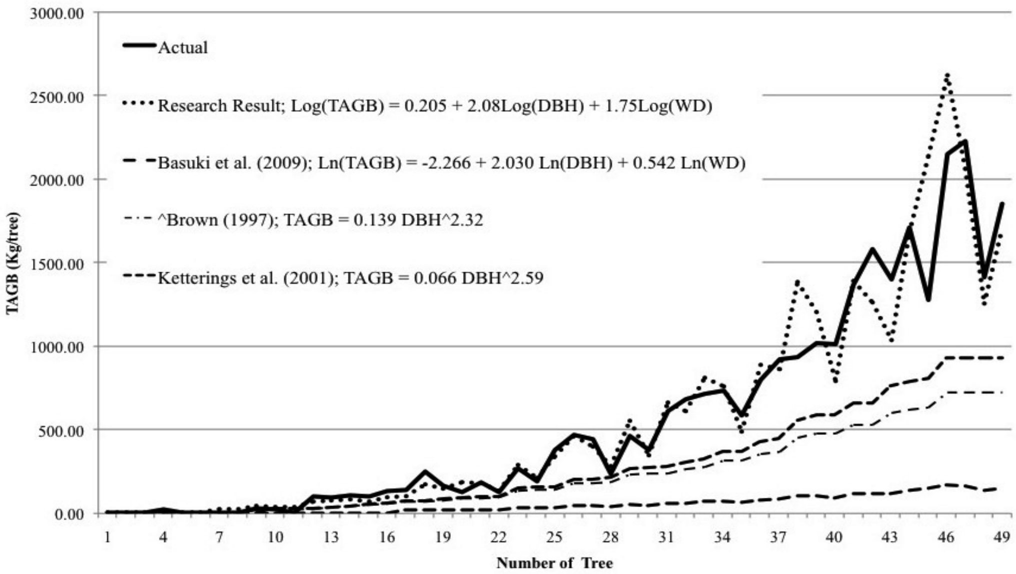

Figure 5. The comparison graph of TAGB estimation values based on published equations

to the upper and lower limits of the observed mean. Wood density is an important factor for estimating the biomass for mixed species, therefore, Log(TAGB) = c + α Log(DBH) + β Log(WD) is the most appropriate equation to estimate total above-ground biomass of mixed commercial species. Further evaluating the allometric model of this mixed commercial species the normal distribution test of the residual is harnessed and the result of this test is showed in Figure 4. Based on this figure, it can be seen that residual points fall near to a straight line in the normal probability plot. According to Fahrmeir et al. (2013), this illustrates that errors during observation are distributed normally in every x-value and the normality of residual assumption is valid.

B. Comparison with Previously Published Equation

From the aspect of model application, allometric equation is specific to certain site and species. Therefore, allometric equation is incomparable for different species and sites, because a different species and site will produce a different tree form and growth rate. But, the structure of the variable and the model form of various allometric equations can be examined to find the highest-level for estimation of the accuracy (Maulana and Asmoro, 2010). In this part, in order to prove that a specific site and species equation will produce the highest estimation accuracy, allometric equation for estimating TAGB of a mixed commercial species from this study is then examined against previously published equations by Basuki et al. (2009), Brown (1997), and Ketterings et al. (2001), as shown in Table 5.

Basuki et al. (2009) developed allometric equations for tropical lowland dipterocarp forest in East Kalimantan. Brown (1997) developed allometric equations for tropical forests using data collected from Kalimantan and other tropical regions. Ketterings et al. (2001) established an allometric equation in mixed secondary forest in Sumatra, but that forest was not classified as Dipterocarp forest. Table 4 shows that the chosen equation in this study has a similar basic form as the other three equations, which were previously published. According to Ketterings et al. (2001), the selection of DBH as independent variable will raise measuring efficiency in the field, and also reduce the uncertainty in the estimation of the result based on established equations. The comparison of estimation value based on equations in Table 5 is shown in Figure 5.

IV. CONCLUSION

Based on data analysis, it can be concluded that the most appropriate equation to estimate TAGB on each genus is Log(TAGB) = c + α Log(DBH), this model uses only a single predictor, the DBH, and produces a range of prediction values closer to the upper and lower limits of the observed mean. Wood density is an important factor for estimating the biomass for mixed species, as a result, Log(TAGB) = c + α Log(DBH) + β Log(WD) is the most appropriate equation to estimate total above-ground biomass of mixed commercial species. Based on the application of the proposed model to the previously published data and the application of the published equation to the current data, it can be concluded that the application of species and site-specific equation must be considered.

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RELATIONSHIP BETWEEN TOTAL TREE HEIGHT AND DIAMETER AT BREAST HEIGHT FOR TROPICAL PEAT SWAMP FOREST TREE SPECIES IN ROKAN HILIR DISTRICT, RIAU PROVINCE

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ABSTRACT

Reliable information on total tree height (*H*) is fundamental of forest resource management and forest ecological studies, including assessment of forest biomass. Adding an *H* variable can improve the performance of the allometric equations of the biomass by reducing the average deviation significantly. However, measuring *H* is relatively complex, less accurate, time consuming, and expensive. Thus, *H* is only measured for sampled trees within the plots, whilst diameter at breast height (DBH) is commonly measured for each tree during the forest inventory. The missing *H* information is usually estimated based on a stand-specific allometric relationship between *H* and DBH (*H-D* model) constructed from sampled trees. Despite extensive studies on *H-D* model for boreal forests and for single-species/plantation forests, few studies have focused on tropical forests. Furthermore, relationship for peat swamp forest tree species, and especially those in Indonesia, have not been widely published. Thus, the objective of this study was to develop site-specific H-D models for tropical peat swamp forests using linearized and non-linear regression functions. The results indicated that the non-linear models outperformed the linearized models based on the statistical parameters and the biological criteria. The modified logistic function (Model 7) is recommended for estimating *H* in the study area as it has comparable model performances to the exponential function (Model 6) and passed the diameter-height point of (0, 1.3). However, all five non-linear models performed equally well and the differences between them were trivial. Further improvements are needed to improve the accuracy, the predictive ability and the geographical applicability of the models by grouping the species, adding stand variables and (or) using advanced techniques of mixed-effect modelling. In addition, model validation should be carried out prior to their application by collecting new datasets from the forest being studied.

Keywords: Site-specific, height-diameter model, linearized and non-linear regression functions, peat swamp forest, Indonesia

ABSTRAK

Informasi tinggi pohon total (*H*) yang dapat dipercaya adalah sangat penting dalam pengelolaan sumberdaya hutan dan kajian-kajian ekologi hutan, termasuk dalam penaksiran biomassa hutan. Penambahan peubah *H* dapat meningkatkan performa dari persamaan alometrik biomassa dengan mengurangi rata-rata penyimpangan secara nyata. Namun demikian, pengukuran *H* adalah rumit, kurang akurat, memakan waktu, dan mahal. Jadi, *H* hanya diukur untuk pohon-pohon contoh di dalam plot, sedangkan diameter setinggi dada (*D*) umumnya diukur untuk setiap pohon selama kegiatan inventarisasi hutan. Informasi *H* yang hilang/tidak lengkap tersebut biasanya diduga berdasarkan suatu hubungan alometrik antara *H* dan *D* yang dibangun dari pohon-pohon contoh. Meskipun banyak kajian tentang pemodelan hubungan antara *H* dan *D* untuk hutan boreal dan untuk hutan jenis tunggal/tanaman, sedikit kajian yang fokus pada hutan

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tropis. Lebih lanjut lagi, hubungan tersebut untuk jenis-jenis pohon di hutan rawa gambut, dan terutama di Indonesia, belum terpublikasi secara luas. Jadi, tujuan dari kajian ini adalah untuk mengembangkan tapak spesifik model *H-D* untuk hutan rawa gambut dengan menggunakan fungsi regresi linier dan non-linier. Hasil dari kajian ini menunjukkan bahwa performa model-model non-linier lebih baik daripada yang linier berdasarkan parameter statistik dan kriteria biologis. Fungsi logistik yang dimodifikasi (Model 7) direkomendasikan untuk menduga *H* di wilayah kajian karena model ini mempunyai performa yang sebanding dengan fungsi eksponensial (Model 6) dan melalui titik diameter dan tinggi dengan nilai 0 cm dan 1,3 m. Namun demikian, kelima model non-linier tersebut mempunyai performa yang sebanding bagusnya dengan perbedaan yang tidak berarti. Perbaikan lebih lanjut dibutuhkan untuk meningkatkan keakurasian, kemampuan prediksi dan penerapan geografis dari model yang dikembangkan dengan mengelompokkan jenis-jenis pohonnya, menambahkan peubah yang mencirikan tegakan dan (atau) dengan menggunakan teknik-teknik lanjut model efek campur. Selain itu, validasi model seharusnya dilakukan sebelum penerapan model yang bersangkutan dengan mengumpulkan suatu dataset baru dari tegakan hutan yang sedang dikaji.

Kata kunci: Tapak-spesifik, model tinggi-diameter, fungsi regresi, hutan rawa gambut, Indonesia

I. INTRODUCTION

Reliable information on total tree height (*H*) is fundamental of forest resource management and forest ecological studies. More specifically, *H* as well as diameter (at breast height (DBH) or at a defined height above-ground level) are two essential tree parameters in forest inventory (Huang et al., 2000; Peng et al., 2001; Peng et al., 2004) and are commonly used in assessing site quality, site productivity, stand dynamics, succession, stand volume, growth and yield, and carbon budgets (e.g. Curtis, 1967; Stout and Shumway, 1982; Hara et al., 1991; Huang et al., 1992; Vanclay, 1992; Cobb et al., 1993; Huang and Titus, 1993; Huang et al., 2000; Peng et al., 2001; Peng et al., 2004; Sharma and Yin Zhang, 2004; Temesgen and Gadow, 2004; Akindele and LeMay, 2006; Sharma and Parton, 2007; Temesgen et al., 2007; Temesgen et al., 2008; Jiang and Li, 2010). In addition, these independent or compound variables in allometric equations are commonly used to predict the above-ground biomass (AGB) (e.g. Chave et al., 2005; Cole and Ewel, 2006; Litton and Kauffman, 2008; Verwer and Meer, 2010). *H* is also a critical variable in process-based and hybrid (combination of empirical and process-based) models such as Formix 3-Q (Ditzer et al., 2000) and TRIPLEX1.0 (Zhou et al., 2005), which simulate the growth of forest stands.

A large number of previous studies relating to forest biomass estimation have noted that adding the *H* variable can improve the performance of the allometric equation of the biomass. For this reason, many have formulated biomass equations that include H in addition to the DBH-only equation (e.g. Crow, 1978; Saldarriaga et al., 1988; Uhl et al., 1988; Brown et al., 1989; Overman et al., 1994; Brown, 1997; Nelson et al., 1999; Ketterings et al., 2001; Chave et al., 2005; Cole and Ewel, 2006; Fehrmann and Kleinn, 2006; Wang, 2006). Although adding H can only marginally increase the coefficient of determination (R^2), but the average deviation ($\overline{S}$ (%)) can be reduced significantly (e.g. ~24% (Nelson et al., 1999)).

While the diameter of a tree can be measured quickly, easily and accurately, the measurement of *H* is relatively complex, less accurate, time consuming, and expensive (Brown et al., 1989; Gower et al., 1999; Huang et al., 2000; Peng et al., 2001; Peng et al., 2004; Segura and Kanninen, 2005; Sharma and Parton, 2007). For these reasons, diameter is commonly measured for each tree during the forest inventory, whereas H is only measured for sampled trees (Huang et al., 2000; Peng et al., 2001; Peng et al., 2004; Chave et al., 2005; Castedo Dorado et al., 2006; Temesgen et al., 2008). A common way to acquire the missing *H* information is by constructing a stand-specific allometric relationship between *H* and DBH from sampled trees and then using the developed equation to predict the H for the rest of the trees being studied (Brown et al., 1989; Huang et al., 2000; Peng et al., 2001; Peng et al., 2004; Chave et al., 2005; Sharma and Parton, 2007; Jiang and Li, 2010).

The relationship between *H* and diameter varies from stand to stand, and within the same stand the relationship varies over time (Curtis, 1967; Paulo et al., 2011). Stand to stand variation occurs due to the differences in site quality (Larsen and Hann, 1987; Wang and Hann, 1988), stand density (Temesgen and Gadow, 2004; Sharma and Parton, 2007) and stand age (VanderSchaaf, 2008). Variation over time within the same stand is caused by the relative position of the trees in a stand (Temesgen and Gadow, 2004) and the spatial distribution pattern (Aguirre et al., 2003; Zhang et al., 2004). Therefore, a conventional simple height-diameter (*H-D*) model (e.g. Yamakura et al., 1986; Brown et al., 1989; Huang et al., 1992; Peng et al., 2001; Okuda et al., 2004; Nogueira et al., 2008) with DBH as the only predictor or independent variable has a local and temporal applicability to the stand from where the fit data was taken (Paulo et al., 2011).

A generalized *H-D* model, with a wider range of geographical applicability, can be constructed by taking into account the stand variables that introduces the dynamics of each stand into the model (Temesgen and Gadow, 2004; Castedo Dorado et al., 2006; Paulo et al., 2011). These include basal area per hectare (ha) (Parresol, 1992; Sánchez et al., 2003; Sharma and Yin Zhang, 2004; Temesgen et al., 2007; Budhathoki et al., 2008), quadratic mean diameter (Sánchez et al., 2003), diameter distribution percentile (Fang and Bailey, 1998; Calama and Montero, 2004), stand density measures (Larsen and Hann, 1987; Sánchez et al., 2003; Calama and Montero, 2004; Sharma and Yin Zhang, 2004; Temesgen and Gadow, 2004; Castedo Dorado et al., 2006), relative tree position variables (Temesgen and Gadow, 2004; Temesgen et al., 2007), site quality variable (Larsen and Hann, 1987; Wang and Hann, 1988; Sharma and Yin Zhang, 2004), the random effects variable (Calama and Montero, 2004; Castedo Dorado et al., 2006; Jiang and Li, 2010) or including fixed dummy variables for regional effects (Huang et al., 2000; Calama and Montero, 2004; Peng et al., 2004).

H-D relationships are commonly developed by applying non-linear biological growth functions such as Chapman-Richards (Richards, 1959), Weibull (Yang et al., 1978), exponential (Ratkowsky, 1990), modified logistic (Ratkowsky and Reedy, 1986), and Schnute (Schnute, 1981). Transformed and untransformed linear functions can be found in the paper by Curtis (1967). Advanced techniques are usually constructed by adding additional variables (e.g. stand variables) into the base model (e.g. Chapman-Richards function). Several studies have compared some linear and (or) non-linear models in the *H-D* relationship studies (e.g. Curtis, 1967; Huang et al., 1992; Zhang, 1997; Fang and Bailey, 1998; Huang et al., 2000; Peng et al., 2001; Sánchez et al., 2003; Temesgen and Gadow, 2004).

Many studies have focused on modelling the relationships between DBH and *H* for boreal forests (e.g. Huang et al., 1992; Peng et al., 2001; Temesgen and Gadow, 2004; Sharma and Parton, 2007; Temesgen et al., 2007; Temesgen et al., 2008) and for single species or plantation forests (e.g. Huang et al., 2000; Soares and Tomé, 2002; Sánchez et al., 2003; Peng et al., 2004; Castedo Dorado et al., 2006; Budhathoki et al., 2008; VanderSchaaf, 2008; Lee et al., 2009; Jiang and Li, 2010; Paulo et al., 2011), but comparatively very few studies have related to tropical forest trees (e.g. Yamakura et al., 1986; Brown et al., 1989; Thomas, 1996; Fang and Bailey, 1998; Bullock, 2000; Okuda et al., 2004; Nogueira et al., 2008; Djomo et al., 2010; Feldpausch et al., 2011). Furthermore, the relationships for peat swamp forest tree species, and especially for those in Indonesia, have not been widely published. Thus, the objective of this study was to develop site-specific *H-D* models for tropical peat swamp forests using linearized and non-linear regression functions.

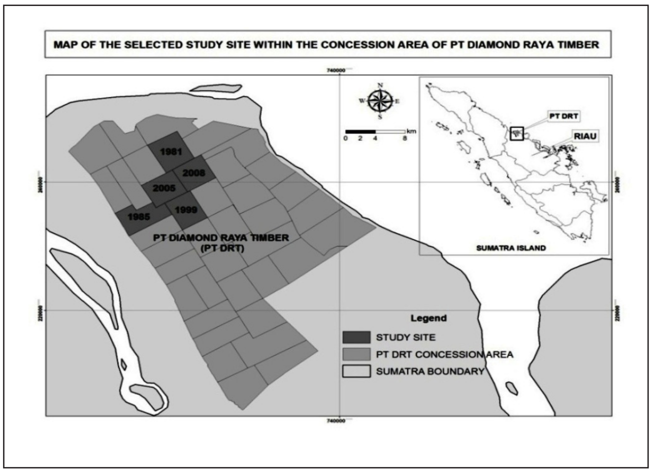


Figure 1. The selected study site within the forest concession area of PT. DRT

II. MATERIAL AND METHOD

A. Study Site

This study was conducted at the selected logging blocks within the concession area managed by PT. Diamond Raya Timber (PT. DRT) in Rokan Hilir District, Riau Province, Indonesia (Figure 1). The area is geographically located between 100°48' – 101°13' East longitude and 1°49' – 2°18' North latitude (Istomo, 2002). It is mainly covered by lowland peat swamp forest, in which the dominant commercial species are balam (*Palaquium obovatum* (Griffith) Engl.), meranti batu (*Shorea uliginosa* Foxw.), ramin (*Gonystylus bancanus* (Miq.) Kurz.), and terentang (*Camnosperma coriaceum* (Jack.) Hallier f. ex v. Steenis). This forest is also the important habitat for the endangered species of the Sumatran tiger (*Panthera tigris sumatrae*).

The topography of the area is flat with the elevation ranging about 0-8 m amsl (meter above mean sea level). In addition, the area is geologically dominated by peat dome along with alluvial and marine groups (Istomo, 2002). The dominant soil type is thick peat soil or histosol (hemic/sapric) with the depth of more than 3 m (Istomo, 2002; Wahyunto et al., 2005), while the minor ones are gley, alluvial and podzolic. Based on the Schmidt and Ferguson climate classification, the area is classified as A type with Q value of 10.1% (Istomo, 2002). The average monthly rainfall ranges from 51.3 to 301.6 mm where the highest occurs in November (301.6 mm) and the lowest in March (51.3 mm). Furthermore, the mean annual temperature ranges from 25 to 27°C and the relative humidity from 79% to 90%.

B. Data Collection

The *H* datasets were collected during the field campaign from August to December 2008. The *H* data can be divided into three sets, according to how they were collected: (1) from the destructively sampled trees to support the generation of allometric biomass equations; (2) following the logging activity by the company, and including felled small trees as a result of logging activity; and (3) using destructive sampling for small trees harvested outside of the plots.

During the field campaign, 286 measurements of DBH and *H* were taken from 38 tree species (listed in Appendix 1). The DBH was measured using a 100-cm diameter-measuring tape before the tree was harvested (for the destructive sampled trees) and after the tree was felled (for trees that had just been logged). Meanwhile, the *H* of a sampled tree (after being felled/cut), including its stump, was measured based on its total length (cut tree + above-ground stumps) using a 50-m measurement tape. The DBH and H range for the sampled trees was 5.2-116.4 cm and 5.39-51.76 m, respectively.

Table 1. Type of *H-D* allometric equation models for *H* estimation developed in this study

Type	Model equation	Source	Model
I	Linearized model		
	$\hat{H} = exp\left(a + b \times ln\left(D\right)\right)$	(Curtis, 1967)	1
	$\hat{H} = exp\left(a + b \times ln\left(D\right) + c \times \left(ln\left(D\right)\right)^2\right)$	(Curtis, 1967)	2
II	Non-linear model		
Chapman-Richards	$\hat{H} = 1.3 + a\left(1 - exp\left(-b \times D\right)\right)^c$	(Richards, 1959; Huang et al., 1992)	3
Weibull	$\hat{H} = 1.3 + a\left(1 - exp\left(-b \times D\right)^c\right)$	(Yang et al., 1978; Huang et al., 1992)	4
Schnute	$\hat{H} = \left[1.3^b + \left(c^b - 1.3^b\right) \times \left(\frac{1 - exp\left(-a\left(D - D_0\right)\right)}{1 - exp\left(-a\left(D_2 - D_0\right)\right)}\right)\right]^{\frac{1}{b}}$	(Schnute, 1981; Huang et al., 1992)	5
Exponential	$\hat{H} = 1.3 + a \times exp\left(\frac{b}{D + c}\right)$	(Ratkowsky, 1990; Huang et al., 1992)	6
Modified Logistic	$\hat{H} = 1.3 + \left(\frac{a}{1 + b^{-1} \times D^{-c}}\right)$	(Ratkowsky and Reedy, 1986; Huang et al., 1992)	7

Notes: $\hat{H}$ is the estimated total tree height (m), exp is *e* raised to the particular i^{th} power, ln is natural logarithm, *D* is the diameter at breast height or DBH (cm), 1.3 is a constant used to account that *D* is measured at 1.3 m (in height from the ground), and *a, b* and *c* are the regression coefficients. For Model 5, D_0 = 0.0 cm and D_2 = 100.0 cm

C. Data Analysis

1. Regression models

Type I (linearized) and Type II (non-linear) regression models were used to develop the *H-D* equations. The type I model consisted of two *H-D* models, whilst the type II model comprised of five *H-D* models. These non-linear models were selected based on the study of Huang et al. (1992) that reviewed 20 non-linear *H-D* models. The mathematical formulation for each model is listed in Table 1. The data analysis for constructing the models was carried out using the JMP® 8.0.1 statistical package developed by SAS Institute Inc. (SAS Institute Inc., 2009).

2. Model selection

The model selection was based on six statistical parameters, where four were explained by Parresol (1999), comprising: (1) the fit index (*FI*), (2) the standard error of estimate in actual unit (S_e), (3) the coefficient of variation (*CV*) in percent, and (4) the corrected mean percent standard error of prediction ($\overline{S}(\%)$) or average (unsigned) deviation (Nelson et al., 1999; Basuki et al., 2009). The fifth parameter is bias (e.g. Temesgen and Gadow, 2004; Jiang and Li, 2010) and the sixth is the Akaike's Information Criterion/*AIC* (Akaike, 1974). The best model will have the lowest *AIC* value. The equations used to calculate those statistical parameters are presented in Table 2.

Table 2. The equations used to calculate the six statistical parameters

Statistical parameter	Equation
$FI = 1 - \left(\frac{RSS}{TSS}\right)$	(1)
$RSS = \sum_{i=1}^{n} \left(Y_i - \hat{Y}_i\right)^2$	(2)
$TSS = \sum_{i=1}^{n} \left(Y_i - \bar{Y}\right)^2$	(3)
$S_e = \sqrt{\frac{RSS}{(n-p)}}$	(4)
$CV = \left(\frac{S_e}{\bar{Y}}\right) \times 100$	(5)
$\bar{S}(\%) = \frac{100}{n} \sum_{i=1}^{n} \frac{\lvert Y_i - \hat{Y}_i \rvert}{Y_i}$	(6)
$B = \left(\frac{\sum_{i=1}^{n} \left(Y_i - \hat{Y}_i\right)}{n}\right)$	(7)
$AIC = C \ln\left(\frac{SS_e}{C}\right) + 2p$	(8)

Notes:
FI is the fit index, RSS is the residual sum of squares, TSS is the total sum of squares, Y_i is the observed data of the i^{th} sample, $\bar{S}(\%)$ is the estimated data of the i^{th} sample, $\bar{S}(\%)$ is the arithmetic mean of the observed data, n is the number of sample observations, S_e is the standard error of estimate in actual unit, p is the number of model parameters, including intercept, CV is the coefficient of variation, $\bar{S}(\%)$ is the corrected mean percent standard error of prediction, B is the bias, AIC is the Akaike's Information Criterion, C is the number of observed data, ln is natural logarithm, and SS_e is the residual sum of squares.

3. Model prediction

For the linearized models, the H and D data were transformed according to the natural logarithm during the model construction. This process introduced a systematic bias of the predicted heights when they were back-transformed to the actual unit, where the estimates usually underestimated the actual values (Chave et al., 2005). For this reason, the predicted height was multiplied by a CF as suggested by Snowdon (1991). The CF ratio estimator formula is mathematically written as in equation (9).

$$CF_{SD} = \left(\frac{\frac{\sum_{i=1}^{n} Y_i}{n}}{\frac{\sum_{i=1}^{n} \hat{Y}_i}{n}}\right) \quad \text{.........................} (9)$$

where CF_{SD} is the correction factors described by Snowdon (1991), Y_i is the observed data of the ith sample, $\hat{Y}_i$ is the estimated data of the i^{th} sample, and n is the number of sample.

III. RESULT AND DISCUSSION

A. Developing Site-specific *H-D* Allometric Models for Peat Swamp Forests

In this study, seven H-D models were developed from 286 destructively sampled mixed tree species in tropical peat swamp forest. Two models were constructed following the linearized function, while five models were developed using the non-linear functions. The summaries of the regression coefficients and the comparison parameters are presented in Table 3. The scatter plots of studentized residuals and predicted heights for all models showed homogenous variance over the full range of the predicted values and no systematic pattern in the variation of the residuals (see Appendix 2). The scatter plot of H against D is presented in Figure 2. The distribution pattern followed the concave shaped curve. For the linearized models (generated by transforming the datasets based on natural logarithmic - ln(H) and ln(D)), the second order polynomial model (Model 2) performed better than Model 1. The difference between Model 1 and Model 2 was prominent. Adding the square of ln(D) to the

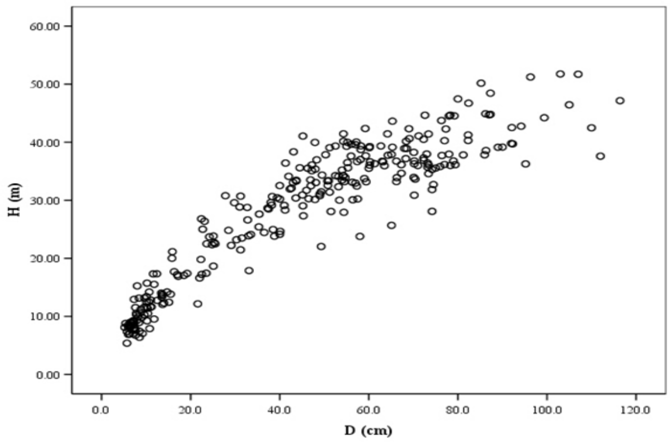
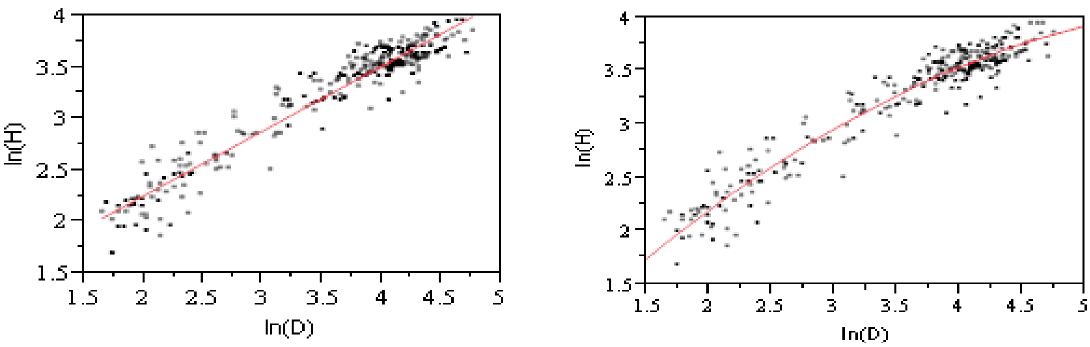


Figure 2. Scatter plot of H (m) against D (cm)



(a) (b)

Figure 3. Scatter plots of transformed natural base logarithmic of *H* (ln(H)) and DBH (ln(*D*)). The curves were produced using (a) Model 1-linear and (b) Model 2-second order polynomial

model improved the index fit (corresponding to R^2) by 2.3% and reduced the standard error (equivalent to *RMSE*), *CV* and $\bar{S}$ (%) by 11.3%, 11.5% and 6.7%, respectively. However, incorporating an extra predictor variable to the model led to an increase in bias (mean residual) of 166.7%. Nonetheless, the actual values were relatively small and negligible (see details in Table 3). *AIC* proved that Model 2 was better than Model 1 indicated by the smaller value of *AIC*. The scatter plots of Model 1 and Model 2 are presented in Figure 3.

For the non-linear models, Model 6 (exponential function) outperformed the other models. Model 6 had slightly better *CV*, $\bar{S}$ (%) and *AIC* values (see Table 3). However, in general, all of the non-linear models fitted the data equally well. Based on the *FI* values, all the models explained approximately 91% of the variations in the *H* caused by changing the *DBH* with the Se of about 3.6 m. The *CV* values for the non-linear models were approximately 12.7% and the $\bar{S}$ (%) values were less than 11%. Model 5 (Schnute function) and Model 6 had lower bias compared to the other models (close to zero), while Model 4 (Weibull function) had the highest bias. Nevertheless, the bias values for all models were relatively small and negligible. The *AIC* values ranged from 733.0 to 734.5. In this regard, Model 3 (Chapman-Richards) had the highest *AIC* value. In general, the non-linear models had similar performances with the second order polynomial function (Model 2).

Table 3. Regression coefficients and comparison parameters for each *H-D* model

Model	Coefficient			Comparison Parameters						*CF*
	Symbol	Value	*SE*	*FI*	*Se*	*CV*	$\bar{S}$(%)	Bias	*AIC*	
1.	*a*	0.9891	0.0383	0.89	4.06	14.39	11.87	0.0024	803.6	1.0046
	b	0.6300	0.0106							
2.	*a*	0.1209	0.1427	0.91	3.60	12.74	11.07	0.0064	736.0	1.0079
	b	1.2198	0.0943							
	c	-0.0920	0.0146							
3.	*a*	46.7505	1.9823	0.91	3.59	12.71	10.96	-0.0036	734.5	NC
	b	0.0218	0.0030							
	c	0.9313	0.0635							
4.	*a*	47.3152	2.4465	0.91	3.59	12.70	10.96	0.0152	734.3	NC
	b	0.0276	0.0030							
	c	0.9466	0.0478							
5.	*a*	0.0214	0.0032	0.91	3.59	12.70	10.96	0.0003	734.4	NC
	b	1.0987	0.0937							
	c	43.1383	0.6528							
6.	*a*	58.4239	2.2809	0.91	3.58	12.67	10.89	-0.0006	733.0	NC
	b	-36.7363	3.6822							
	c	10.9102	1.8363							
7.	*a*	59.5266	4.6786	0.91	3.58	12.68	10.95	0.0093	733.2	NC
	b	0.0176	0.0023							
	c	1.0690	0.0721							

Notes: *SE* = standard error of the coefficient, *FI* = Fit Index, *Se* = Standard error in actual unit, *CV* = Coefficient of Variation, $\bar{S}$(%) = Average deviation, *AIC* = Akaike's Information Criterion, *CF* = correction factor, NC = Not Corrected

Based on the *H-D* curves for the non-linear models (Figure 4), it was observed that the curves were sigmoidal or S-shaped, which is typical of the general pattern of the tree's biological growth. However, the inflection points were not apparent. It is also important to note that the five non-linear models fitted to the same dataset produced different asymptote coefficients (indicated by the coefficient a in Table 3, with the exception of Schnute function of Model 5 in which the asymptotic coefficient was approximate to the coefficient c). In general, two asymptote values can be grouped from Table 3: (1) those close to 50 m values, being the Chapman-Richards, Weibull and Schnute functions (Model 3, 4 and 5), and (2) those close to 60 m values, being the exponential and modified logistic functions (Model 6 and 7). Model 5 (Schnute function) had the lowest asymptote value, whereas Model 7 (modified logistic function) had the highest one.

Figure 5 provides a graphical visualization of the curve comparison among the models. For lower DBH values (approximately up to 25 cm), all the models tended to generate relatively similar estimates of *H*. Where the DBH ranged from 25 cm to 65 cm, Model 1 produced lower estimates of *H*, while other models resulted in similar values of *H*. Where the DBH exceeded 65 cm, Model 1 deviated increasingly from the other models. Model 2 tended to give slightly larger estimates than the non-linear models at DBH above 100 cm. However, there was no apparent difference in height estimates among the non-linear models as can be observed from Figure 5.

The developed models had generally low $\bar{S}$ (%) less than 16% for all DBH classes (Table 4). All the site-specific equations tended to have a higher $\bar{S}$ (%) value for smaller DBH classes. For DBH class, less than 10 cm, the $\bar{S}$ (%) ranged from 14.7% to 15.9%, while for DBH class of 10-30 cm, the $\bar{S}$ (%) ranged from 14.0% to 14.5%. These $\bar{S}$ (%) values decreased

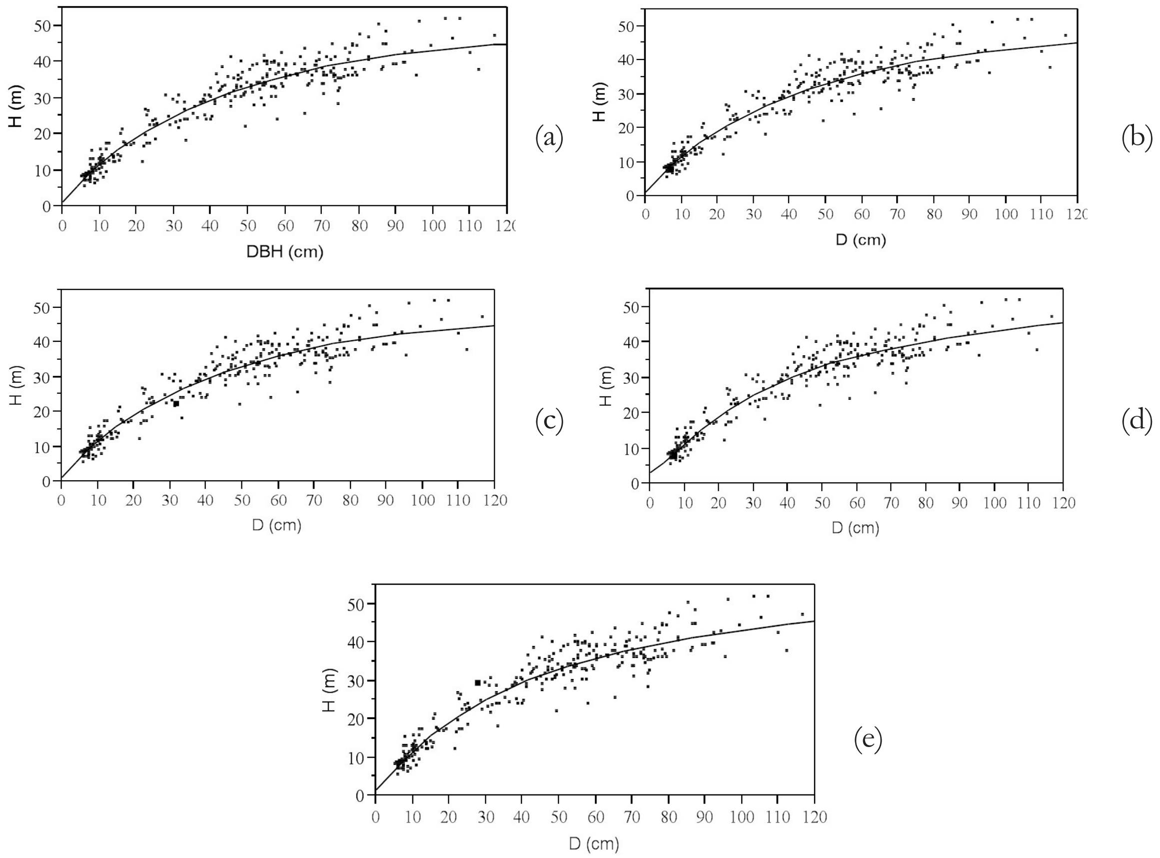


Figure 4. Scatter plots of *H* (m) and *D* (cm). The curves were produced by: (a) Model 3-Chapman-Richards; (b) Model 4-Weibull; (c) Model 5-Schnute; (d) Model 6-Exponential; and (e) Model 7-Modified logistic

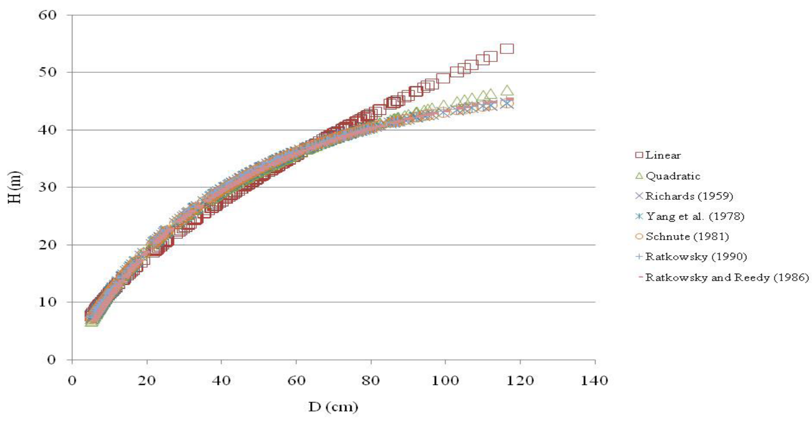


Figure 5. Predicted *H* using the seven *H-D* models (square: linear, triangle: quadratic, cross: Chapman-Richards, star: Weibull, plus: exponential, and minus: modified logistic)

for larger DBH classes with common values of less than 11%, except for Model 1 (11.38% and 14.99% at DBH classes of 70-90 cm and more than 90 cm, respectively). In general, Model 6 provided the most precise estimate of H within lower DBH classes (≤ 30 cm) and Model 7 produced the most precise prediction at larger DBH classes (> 50 cm). For DBH class of 30-50 cm, Model 3 and Model 5 gave the same $\overline{S}$ (%) value (10.05%). However, this value

Table 4. A summary of the $\overline{S}$ (%) per DBH classes (cm) for each H-D model

Model	Mean $\overline{S}$ (%) Per DBH classes (cm)					
	Ø <= 10	10 < Ø <= 30	30 < Ø <= 50	50 < Ø <= 70	70 < Ø <= 90	Ø > 90
	n = 42	*n* = 53	*n* = 58	*n* = 70	*n* = 50	*n* = 13
Model 1	15.91	14.07	10.82	8.41	11.38	14.99
Model 2	15.00	14.47	10.14	8.14	9.90	8.82
Model 3	14.89	14.16	10.05	8.16	9.82	8.83
Model 4	14.89	14.18	10.06	8.15	9.79	8.81
Model 5	14.88	14.18	10.05	8.16	9.81	8.82
Model 6	14.70	14.00	10.08	8.16	9.72	8.75
Model 7	14.75	14.30	10.10	8.14	9.71	8.69

Notes:
Ø = DBH (cm) and *n* = number of sampled tree

was relatively similar to the ones produced by Model 4 and Model 6, with those being 10.06% and 10.08%, respectively.

B. *H-D* Models for Tropical Peat Swamp Forest Tree Species

H is an important tree parameter for many forestry related applications not only for forest resource management but also for forest ecological studies. Measuring H of a standing tree in a dense forest stand, however, is challenging, time consuming and expensive (Brown et al., 1989; Gower et al., 1999; Huang et al., 2000; Peng et al., 2001; Brown, 2002; Peng et al., 2004; Segura and Kanninen, 2005; Sharma and Parton, 2007), especially in tropical forests with many features, like multi-species, multi-storey and multi-age. In addition, direct measurement of H is usually inaccurate because the top of the tree often cannot be easily observed and measured (Brown, 2002). As a result, *H* is only collected for sampled trees, while the DBH is collected for all the trees in the measurement plots during the regular forest inventory (Huang et al., 2000; Peng et al., 2001; Peng et al., 2004; Chave et al., 2005; Castedo Dorado et al., 2006; Temesgen et al., 2008). In tropical peat swamp forests, collecting accurate *H* data is almost impossible without felling the tree. This is because of the terrain condition that was almost entirely inundated and the multi-layer of the forest canopy makes it difficult to observe the top of the tree to be measured. Therefore, models or functions that relate *H* to DBH have a crucial role in providing estimates of the missing information of the H of the trees (Brown et al., 1989; Huang et al., 2000; Peng et al., 2001; Peng et al., 2004; Chave et al., 2005; Sharma and Parton, 2007; Jiang and Li, 2010), considering the strong correlation between these two tree parameters.

Although many *H-D* models are available for boreal forest tree species (Huang et al., 1992; Sharma and Parton, 2007; Temesgen et al., 2008) and for single species or plantation forests (e.g. Soares and Tomé, 2002; Peng et al., 2004; Castedo Dorado et al., 2006; VanderSchaaf, 2008; Lee et al., 2009; Jiang and Li, 2010; Paulo et al., 2011), but relatively few models are available for tropical forest tree species (e.g. Yamakura et al., 1986; Brown et al., 1989; Fang and Bailey, 1998; Bullock, 2000; Okuda et al., 2004; Djomo et al., 2010; Feldpausch et al., 2011). In addition, currently there are no publications available on *H-D* models for peat swamp forests, specifically in Indonesia. Considering that *H* can improve the performance of allometric biomass equations (Brown et al., 1989; Brown, 2002), this study will contribute to increase the accuracy of biomass assessment in addition to the forest management's purpose.

The results of this study indicated that the non-linear models outperform the linearized models. Model 1, which is the simplest model with one predictor, has the poorest model performance with an *FI* of only 0.89 (corresponding to a 0.93 of R^2 in linear regression), an S_e of 4.1 m and an $\overline{\varsigma}$ (%) of 11.9%. However, the R^2 of Model 1 was much higher than that of the equation from Brown et al. (1989), which was only 0.61. The lower R^2 value of the *H-D* model presented by Brown et al. (1989) can be attributed to the high variability of the collected *H-D* dataset, which came from a wide range of geographical area (Venezuela, Puerto Rico and Papua New Guinea), considering that the *H-D* relationship varies from stand to stand and within the same stand over time (Curtis, 1967; Temesgen and Gadow, 2004; Temesgen et al., 2007; Temesgen et al., 2008; Paulo et al., 2011) and is influenced by the conditions of the local environment (Peng et al., 2004). The second order polynomial function (Model 2) resulted in a better performance, with the *FI* of 0.91, the S_e of 3.6 m and the $\overline{\varsigma}$ (%) of 11.1%. In general, this model had a similar performance to the non-linear models developed in this study. However, previous studies did not recommend the polynomial equations for growth and yield or *H-D* relationship because they are devoid of any biological interpretation (Zeide, 1993) and do not have meaningful parameters from a forestry perspective (Lei and Zhang, 2004).

Many non-linear theoretical models (e.g. the Chapman-Richards, the Weibull, the Schnute, the exponential and the modified logistic) have been used to model *H-D* relationships (e.g. Huang et al., 1992; Zhang, 1997; Fang and Bailey, 1998; Peng et al., 2001) because theoretical models have an underlying hypothesis associated with the cause or the function of the phenomenon described by the response variable (Vanclay, 1994). However, there is no general agreement on the best non-linear base model for *H-D* relationship studies.

In this regard, the Chapman-Richards growth function has been employed more often than any other models (e.g. Peng et al., 2004; Sharma and Yin Zhang, 2004; Pilli et al., 2006; Sharma and Parton, 2007; Temesgen et al., 2008), because of its accuracy (Zeide, 1993; Lei and Zhang, 2004). In this study, the results from model comparison parameters suggested that all five non-linear models fitted the *H-D* dataset equally well (Table 3) with the *FI*, the S_e and the $\overline{\varsigma}$ (%) values being 0.91, 3.58-3.59 m and 10.89%-10.96%, respectively. This is consistent with the findings reported by Huang et al. (1992) for major Alberta tree species, by Zhang (1997) for ten tree species in inland Northwest of the United States, by Peng et al. (2001) for nine tree species of Ontario's boreal forest, and by Krisnawati et al. (2010) for *Acacia mangium* plantation forest in South Sumatra, Indonesia. Based on the model comparison parameters, the Chapman-Richards equation (Model 3) resulted in the poorest performance compared to other models but gave a lower bias than the Weibull (Model 4) and modified logistic functions (Model 7). In general, however, the differences among the models were trivial.

In developing the models, reasonable biological criteria in addition to the data-related criteria in the model selection needed to be considered (Yuancai and Parresol, 2001). In this regard, the model should represent the biological process of tree growth. From a biological point of view, a height curve should exhibit a sigmoid or S-shaped pattern and possess three properties: (1) monotonic increment, (2) inflection point, and (3) asymptotic value (Parresol, 1992; Yuancai and Parresol, 2001). In this study, all five non-linear models produced *H-D* curves that followed a sigmoid or S-shaped pattern as presented in Figure 4. However, the inflection points were not clearly visible. This was probably because the *H-D* dataset did not contain DBH values lower than 5 cm, which constitutes the early stage of tree growth as suggested by Parresol (1999), Yuancai and Parresol (2001) and Pilli et al. (2006). Yuancai and Parresol (2001) indicated that the five models suggested by Huang et al. (1992), which were used in this study, produced

S-shaped curves with inflection points. The Chapman-Richards (Model 3), Weibull (Model 4) and Schnute (Model 5) equations had relatively similar asymptotes (close to 50 m). The same findings were reported by Huang et al. (1992), Zhang (1997) and Peng et al. (2001). On the other hand, the exponential (Model 6) and the modified logistic (Model 7) functions had similar asymptotes of close to 60 m. Huang et al. (1992) reported the same finding for major Alberta tree species. The asymptotic value of close to 60 m is more realistic for the study area considering that the maximum height in the dataset was 51.76 m (Appendix 1).

Paulo et al. (2011) suggested that the *H-D* functions should pass through the point (*D*=0, *H*=1.30 m) to prevent negative height estimates for small trees and/or to guarantee a good estimation for small trees. In addition, it is important to meet a theoretical assumption that tree DBH should be zero when H is 1.30 m because the DBH is defined as the tree diameter at breast height or 1.30 m from the ground (Fang and Bailey, 1998). Based on the extrapolation, all the non-linear models passed through the point of diameter-height (0, 1.3) with the exception of the exponential function of Model 6 (0, 3.31). Soares and Tomé (2002) found poor height predictions for young stands from the equation that not restricted to the point of diameter-height (0, 1.3). Therefore, Model 7 (the modified logistic) is better suited for estimating H in peat swamp forests, although it is the second best equation after Model 6 in terms of the statistical parameters. Huang et al. (2000) found the modified logistic function to be the best model for white spruce in boreal forests.

C. The Applicability of The Developed Models and The Possible Improvements

There are two types of *H-D* equations based on their applications: (1) local and (2) generalized (Soares and Tomé, 2002). The local equations are normally only developed based on DBH and can be applied to the stand where the dataset was collected, while the generalized or regional equations are constructed using DBH and other stand variables and can be applied at the regional level. Considering that the developed models in this study used only DBH as a predictor, their application is restricted to the study area where the dataset was gathered. In addition, it is relatively safe to perform an extrapolation for the non-linear *H-D* models because *H* normally has a maximum during its life span which is approximated by the asymptote coefficients (Yuancai and Parresol, 2001). Therefore, *H* will not increase after the maximum height is reached, although the DBH will increase continuously. Thus, using the models to estimate *H* for larger DBH beyond the validity range will not result in large errors. For example, *H* extrapolated from a DBH of 200, 250 and 300 cm was 47.5, 47.9 and 48.0 m, respectively (for Model 3-Chapman-Richards), 47.9, 48.3 and 48.5 m, respectively (for Model 4-Webull), 47.6, 48.0 and 48.2 m, respectively (for Model 5-Schnute), 50.4, 52.1 and 53.2 m, respectively (for Model 6-exponential), and 51.0, 52.8 and 54.1 m, respectively (for Model 7-modified logistic). These ranges of *H* values are still realistic for peat swamp forest tree species (see Appendix 1). *H* should not be extrapolated using the linear models because these models do not possess asymptotic values. Therefore, based on the linear models, *H* will increase when the DBH increases without any limit.

In this study, the *H-D* models were developed from 38 tree species with variable *H-D* characteristics. For example, *Cratoxylum arborescens* and *Tetramerista glabra* species tended to have lower tree heights for the same DBH, while *Shorea uliginosa* and *Gonystylus bancanus* tended to have greater heights. For a DBH of 95.2 and 112.0 cm, *H* for *C. arborescens* were 36.27 and 37.60 m, respectively, which were significantly lower than those of other species with typical heights of 39.00-51.00 m. *H* for *T. glabra* with DBH of 58.0, 65.1 and 74.2 cm were 23.76, 25.68 and 28.09 m, respectively, which were much lower than those of other species with common heights of 33.00-41.00 m. For the DBH of 41.3 and 43.1 cm, the total tree heights for *S. uliginosa* were 36.41 and 38.35 m, respectively, which were significantly taller than those of other species with typical heights of 28.00-33.00 m. The total tree height for *G. bancanus* with DBH of 47.9 cm was 39.97 m, which was much taller than those of other species with common heights of 30.00-36.00 m. As a consequence, these species had larger studentized residuals, more than 2.5 standard deviations (Appendix 2). Thus, grouping the species based on their *H-D* characteristics and then constructing *H-D* models for each species group may improve the model performance.

The improvement in the *H-D* models can also be achieved by incorporating stand variables as reported by various authors from previous studies. Such variables may include basal area per ha (Parresol, 1992; Sánchez et al., 2003; Sharma and Yin Zhang, 2004; Temesgen et al., 2007; Budhathoki et al., 2008), quadratic mean diameter (Sánchez et al., 2003), diameter distribution percentile (Fang and Bailey, 1998; Calama and Montero, 2004), stand density measures (Larsen and Hann, 1987; Sánchez et al., 2003; Calama and Montero, 2004; Sharma and Yin Zhang, 2004; Temesgen and Gadow, 2004; Castedo Dorado et al., 2006), relative tree position variables (Temesgen and Gadow, 2004; Temesgen et al., 2007), and site quality variables (Larsen and Hann, 1987; Wang and Hann, 1988; Sharma and Yin Zhang, 2004) or fixed dummy variables can be included for regional effects (Huang et al., 2000; Calama and Montero, 2004; Peng et al., 2004). The inclusion of these stand variables improved H estimates and the applicability of the models as long as the required stand variables were available (Temesgen et al., 2007; Jiang and Li, 2010). However, when the additional stand variables are unavailable for a forest stand being studied, the application of the generalized model becomes limited (Jiang and Li, 2010).

Recent studies reported that the application of mixed-effect modelling in the development of *H-D* models improved the performance and the predictive ability of the models (Calama and Montero, 2004; Castedo Dorado et al., 2006; Sharma and Parton, 2007; Budhathoki et al., 2008; Temesgen et al., 2008; Lee et al., 2009; Jiang and Li, 2010; Paulo et al., 2011). In contrast to traditional regression techniques, mixed-effect models allow fixed and random parameters to be estimated simultaneously, providing consistent estimates of the fixed parameters and their standard errors (Jiang and Li, 2010). In addition, these models also explain the correlation structure of the data and provide realistic variance estimates for stochastic simulation and for modelling natural variability (Temesgen et al., 2008). The inclusion of random parameters enables the models to capture more variation among and within stands (Jiang and Li, 2010). By calibrating the random parameters through a sub-sample of tree height measurement from a particular forest stand, the mixed-effect model can be used to predict tree heights from a new stand (Temesgen et al., 2008; Jiang and Li, 2010). Therefore, the application of mixed-effect models will also improve the geographical applicability of the H-D models.

IV. CONCLUSION

In this study, seven *H-D* models were developed based on the application of linearized and non-linear regression functions. The non-linear models outperformed the linearized models based on the statistical parameters and the biological criteria. All five non-linear models performed equally well and the differences between them were trivial. However, the modified logistic function (Model 7) is recommended for estimating *H* in the study area as it has comparable model performances to the exponential function (Model 6) and passed the diameter-height point of (0, 1.3). Further improvements, however, are needed to improve the accuracy, the predictive ability and the geographical applicability of the model by grouping the species, adding stand variables and (or) using advanced techniques of mixed-effect modelling. In addition, model validation should be carried out prior to their application by collecting a new dataset from the forest being studied.

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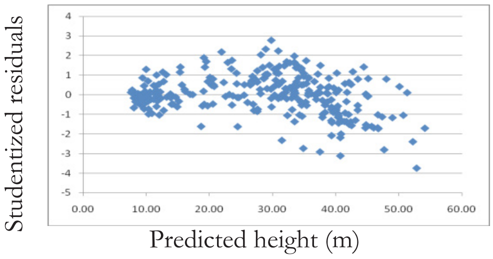
APPENDIX 1. Tree species used to develop site specific *H-D* models and their statistical summaries

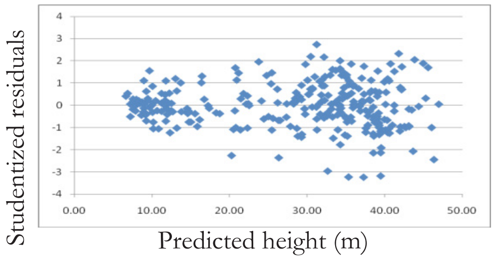
No.	Species Name		Statistical summary								
	Local	Scientific	D_{min} (cm)	D_{max} (cm)	D_{mean} (cm)	D_{SD} (cm)	H_{min} (m)	H_{max} (m)	H_{mean} (m)	H_{SD} (m)	*n*
1	Arang-arang	*Myristica lowiana* King.	7.3	67.3	48.9	24.1	7.8	39.3	30.2	12.6	8
2	Asam-asam	*Santiria griffithii* (Hook.f.) Engl.	8.5	14.0	11.3	3.9	10.5	12.3	11.4	1.2	2
3	Balam	*Palaquium obovatum* (Griffith) Enql.	7.6	61.3	36.0	16.1	7.8	36.3	25.2	8.3	15
4	Bintangur	*Calophyllum soulattri* Burm.f.	7.8	7.8	7.8	NA	10.5	10.5	10.5	NA	1
5	Darah-darah	*Horsfieldia glabra* (Blume) Warb.	5.4	33.0	17.7	12.0	7.4	26.6	16.0	8.0	7
6	Durian burung	*Durio carinatus* Masters	6.4	63.5	43.3	32.0	8.9	39.0	27.9	16.5	3
7	Geronggang	*Cratoxylum arborescens* (Vahl.) Blume.	6.3	112.0	66.1	26.2	6.9	39.1	32.0	8.5	19
8	Jambu-jambu	*Eugenia* sp. L.	7.8	33.1	18.7	8.5	9.3	19.8	15.3	3.8	8
9	Jangkang	*Xylopia malayana* Hook.f. et. Th.	10.1	10.7	10.4	0.4	13.4	14.2	13.8	0.5	2
10	Kapas-kapas	*Unknown*	35.3	47.2	41.3	8.4	25.4	35.1	30.2	6.8	2
11	Katiau	*Ganua motleyana* (de Vriese) Piere ex D.	24.2	37.5	30.9	9.4	23.7	28.5	26.1	3.3	2
12	Kelat	*Carallia brachiata* (Lour.) Merr.	8.3	25.1	14.0	6.9	7.9	23.8	14.5	6.3	5
13	Kenari	*Santiria laevigata* Blume.	6.7	14.7	10.5	4.0	9.0	14.2	10.8	2.9	3
14	Keranji	*Dialium modestum* (v.Steen) Stey	5.7	5.7	5.7	NA	7.4	7.4	7.4	NA	1
15	Kopi-kopi	*Gardenia* sp.	7.6	7.6	7.6	NA	6.7	6.7	6.7	NA	1
16	Mahang	*Macaranga semiglobosa* J.J.S.	6.6	12.4	9.5	4.1	8.5	17.3	12.9	6.2	2
17	Manggis-manggis	*Garcinia celebica* (Burm.) L.	6.0	31.2	20.2	10.8	6.9	21.4	16.0	6.3	4
18	Medang telor	*Lindera subumbliiflora* Kosterm.	7.3	19.2	12.2	6.2	12.9	17.4	15.3	2.2	3
19	Mengkal udang	*Timonius* sp.	7.0	7.0	7.0	NA	7.0	7.0	7.0	NA	1
20	Meranti anak	*Spondias pinnata* (J. Konig ex L. f.) Kurz	8.4	103.0	63.9	30.0	8.9	51.7	34.8	12.5	12
21	Meranti batu	*Shorea uliginosa* Foxw.	6.4	92.0	56.2	18.0	6.4	50.1	35.6	7.5	64
22	Meranti bunga	*Shorea teysmanniana* Dyer ex Brandis	9.0	96.3	54.2	24.3	9.8	51.2	33.1	11.2	12
23	Milas	*Parastemon urophyllum* (Wallich. ex A. DC) A.DC	7.6	54.5	27.6	16.9	11.5	33.4	24.9	7.9	7
24	Nangka-nangka	*Neoscortechinia kingii* Hook. F.	6.4	11.0	8.7	3.3	8.0	11.6	9.8	2.5	2
25	Nyatoh	*Palaquium rostratum* (Miq.) Burck.	38.5	38.5	38.5	NA	24.9	24.9	24.9	NA	1
26	Pasak linggo	*Aglaia rubiginosa* (Hiern.) Pannell.	8.0	43.0	27.4	16.1	13.6	33.0	24.7	9.4	5
27	Pasir-pasir	*Ilex macrophylla* Hook. F.	6.4	54.4	23.4	17.8	7.6	27.9	16.6	7.9	10
28	Pisang-pisang	*Mezzettia parviflora* Becc.	7.3	54.3	37.0	17.0	9.1	41.4	27.8	9.7	9
29	Pulai	*Alstonia pneumatophora* Backer ex den Berger	10.4	116.4	77.5	21.2	10.5	51.7	39.5	7.6	29
30	Punak	*Tetramerista glabra* Miq.	9.2	74.2	51.2	25.2	7.0	28.0	21.3	8.2	5
31	Ramin	*Gonystylus bancanus* (Miq.) Kurz.	5.2	89.0	48.9	24.7	8.1	40.0	31.3	10.1	13
32	Selumar	*Jackiopsis ornata* (Wallich) Ridsd.	8.4	11.2	9.8	2.0	11.6	13.1	12.4	1.0	2
33	Serapat	*Calophyllum macrocarpum* Hook. F.	47.0	73.4	62.9	12.5	32.5	40.5	35.7	3.5	4
34	Simpur	*Dillenia excelsa* (Jack) Gilg.	6.0	35.4	17.0	16.0	8.1	27.6	15.7	10.3	3
35	Suntai	*Palaquium dasyphyllum* (de Vriese) Pierre ex Dubard	7.3	7.3	7.3	NA	8.4	8.4	8.4	NA	1
36	Terentang	*Campnosperma coriaceum* (Jack.) Hallier f. ex v. Steenis	9.6	52.5	33.8	14.8	10.2	34.2	23.4	8.9	10
37	Terpis	*Polyalthia glauca* (Hassk.) F. v. Mueller	5.7	27.8	15.7	11.1	5.3	30.7	18.0	12.6	4
38	Timah-timah	*Ilex pleiobrachiata* Loes.	6.0	13.5	9.5	3.4	7.8	13.3	10.6	2.8	4
		All species	**5.2**	**116.4**	**45.2**	**27.5**	**5.3**	**51.7**	**28.2**	**12.0**	**286**

Notes : *D* = diameter at breast height, *H* = total tree height, *n* = number of sample, *min* = minimum, *max* = maximum, *mean* = average, *SD* = standard deviation, and *NA* = not applicable

APPENDIX 2. Scatter plots of regression studentized residuals against predicted height for each developed model: (a) Model 1, (b) Model 2, (c) Model 3, (d) Model 4, (e) Model 5, (f) Model 6, and (g) Model 7



(a)



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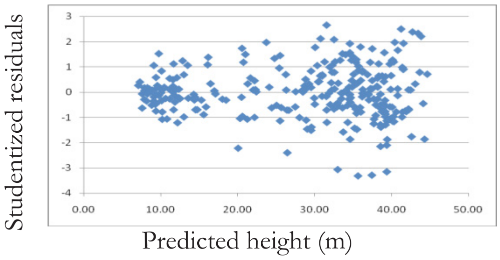

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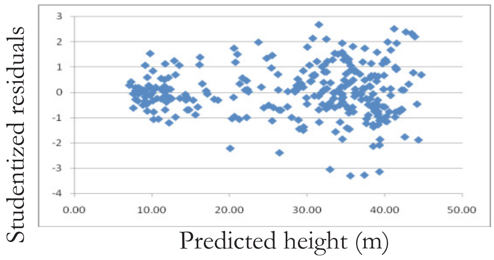

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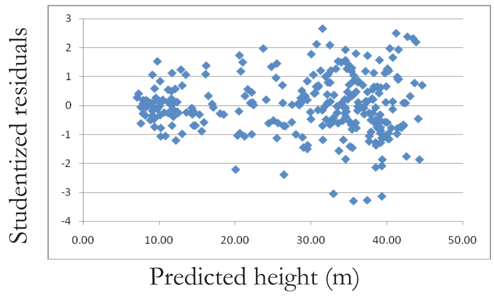

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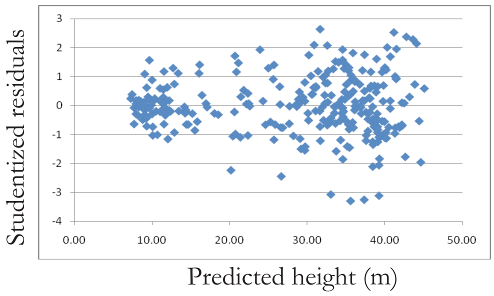
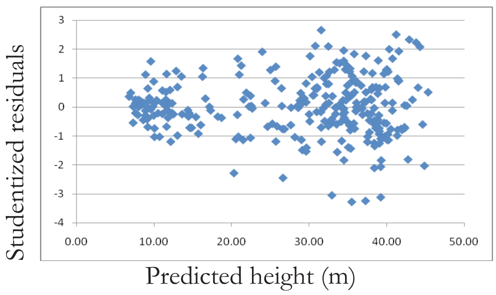


(f)



(g)

THE EFFECT OF SAPPAN WOOD (*Caesalpinia sappan* L.) EXTRACT ON BLOOD GLUCOSE LEVEL IN WHITE RATS

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ABSTRACT

Sappan wood or kayu secang (*Caesalpinia sappan* L.) was reported of having medicinal properties, such as natural antioxidant, relieve vomiting of blood, and mix of ingredients for malaria drugs. The research was conducted to study the influence of ethanol extract from sappan wood on blood glucose level of white rats. The study of the blood glucose level in rats was carried out by using glucose tolerance method. It was measured by Refloluxs (Accutrend GC) with Chloropropamide 50 mg/200 g BW (Body weight) as positive control. The ethanol extracts were used in various concentrations 10, 20, 30, 40 and 50 mg/200 g BW per-oral and was observed every hour, beginning one hour before to 7 hours after the extract being administered. The results showed that treatment of ethanol extract of sappan wood by administer doses gave remarkable effect on the blood glucose level in white rat. It reduced the glucose level in the blood compared to the negative and positive control. Treatment of dose 30 mg/200 g BW gave similar effect to positive controls, while a dose of 50 mg/200 g BW gave lower blood glucose level (93 mg/dl) than the positive controls.

Keywords: Sappan wood, ethanol extract, blood glucose level, white rat

ABSTRAK

Kayu Sappan atau kayu secang (*Caesalpinia sappan* L.) dilaporkan memiliki banyak manfaat sebagai tanaman obat, misalnya untuk antioksidan alami, meredakan muntah darah, dan bahan-bahan campuran untuk obat malaria. Penelitian ini bertujuan untuk mengetahui pengaruh ekstrak etanol dari kayu sappan pada kadar glukosa darah tikus putih. Tingkat glukosa darah pada tikus putih dilakukan dengan menggunakan metode toleransi glukosa. Ini diukur dengan Refloluxs (Accutrend GC) dengan kloropropamida 50 mg/200 g BB (berat badan) sebagai kontrol positif. Ekstrak etanol yang digunakan dalam berbagai konsentrasi 10, 20, 30, 40 dan 50 mg/200 g BB per-oral dan diamati setiap satu jam dan dimulai satu jam sebelum sampai 7 jam setelah ekstrak diberikan. Pemberian ekstrak 30 mg / kg BB tidak berbeda nyata dengan kontrol positip, sedang pemberian ekstrak 50 mg/200gBW menurunkan kadar glukosa darah (93 mg/dl) dibandingkan dengan kontrol positif.

Kata kunci: Kayu secang, ekstrak etanol, kadar glukosa darah, tikus putih

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I. INTRODUCTION

Indonesian forests provide more than 9,606 species of medicinal plants (Pranoto, 1999). Most of them are native to Indonesia and many of the plants are endemic (Walujo, 2008). The high diversity of the plant species also has a great potential for the discovery of bioactive compounds they contain. Several studies have successfully revealed the antioxidant potential of some Indonesian plants (Hakim et al., 2008; Rohman et al., 2006; Amrun and Umiyah, 2005; Praptiwi et al., 2006). Three criteria must be fulfilled when extracting plants to medicine materials, i.e. quality, safety and efficacy. Advanced research must be done until the discovery of effective and simple drugs (Chairul, 2003).

Sappan wood or kayu secang (*Caesalpinia sappan* L.) is one of the traditional medicine materials. This species is a type of flowering tree in the group of the Fabaceae legume family. Sappan wood is native to Southeast Asia and the Malay archipelago. Common names of sappan are patanga-chekke sappanga (Kanada name) and sumu (Japanese). Sappan belongs to the same genus or synonym with *Caesalpinia echinata* or braziel wood (*C. echinata*), and was originally called "brezel wood" in Europe (Anonymous, 1998; Xu and Lee, 2004). Furthermore, this wood was a major trading goods during the 17th century, when it was exported from Southeast Asian nations (especially Siam) to Japan.

The sappan plant is being used worldwide for a large number of traditional medicinal purposes. This plant produces brazilin that is found to be responsible for several of its biological activities (Badami et al., 2004). Modern day research confirmed it's cytotoxic from heartwood (Badami et al., 2003), antitumor from part of stem and heartwood (Dhawon et al., 1980; Itokawa et al., 1990 *in* Badami et al., 2004), anti-inflammatory from heartwood (Hikino et al., 1977 *in* Badami et al., 2004), anti-coagulant properties (Takaoka and Tagakaki, 1995), and blood vomiting cure and drug treatment after child birth (Aulia, 2002). According to Aviratnant and Pongpan (1983) and Yadava et al. (1978) in Badami et al. (2004), the essential oil obtained from the leaves, the 95% ethanol and water extracts of the wood showed strong antibacterian activity againts *Bacillus subtilis*, *Staphylococcus aureus*, *Salmonella typhosa* and *Escherichia coli*. Prawirosujanto (1977) and Sugati (1981) said that the bark of this plant had been used for folk medicine as anti-diarrhea, anti-microbial, expectorant, anti-pyretic, cataract, and tonic. Xu and Lee (2004) reported that brazilin from *C. sappan* is antibacterial and it has the potential to be developed into an antibiotic.

This paper studies the potential use of sappan wood for reducing blood glucose level in white rats. The analysis was carried out to see the influence of ethanol extract from sappan wood on blood glucose level of white rats.

II. MATERIAL AND METHOD

A. Plant Materials and Experimental Animals

1. Sappan wood (*Caesalpinia sappan* L.) was collected from Kemangkon village, Purbalingga, Central Java and was identified at the Herbarium Bogoriense, Research Center for Biology, Cibinong. Authentic specimen was deposited at the same Institution.
2. The experimental animals used were 2.5 to 3 months male white rats (*Ratus ratus*) Winstar strain of 200 – 300 g weight. Before being tested the animals were fed for 14 days to get the expected weight (Malole and Purnomo, 1989).

B. Sample Preparation

The preparation of samples and the testing procedures in the experiment used the Taylor Method (Chairul, 2003).

1. The sappan wood extract

Preparation of extract : 1 kg powder of air dried sappan wood was macerated by 95% ethanol for 24 hours, until the solvent covered the surface of the plant material.

After 24 hours, the filtrate was concentrated under vacuum rotary evaporator. This work was repeated 2 or 3 times until the colorless solvent was obtained. Filtrate was combined and concentrated. Then, the extracts were dried by freeze dryer to get dry sappan extracts.

2. The glucose suspension

2.1. 1% CMC suspension

1 g CMC was balanced on watch glass, developed in mortar by hot water and grinded until it was homogenous and 100 ml purified water was added.

2.2. 1% glucose stock solution

1 g glucose stock solution anhydrate was put into a 100 ml volumetric flask, 50 ml aquadest was added, it was shaken and 100 ml aquadest was added, and than it was shaken well until the glucose solved. The glucose solution from the 100 ml volumetric flask was removed to a 150 ml beaker glass, 2% active carbon was added, then shaken well and heated for 30 minutes on water bath, then filtered and kept in the infuse bottle.

2.3. Standard glucose solution

1% glucose stock solution (2.2) was pipetted and put into a 100 ml volumetric flasks, and 100 ml aquadest purified water was added to each volumetric flask, shaken well and than homogenized. This was done to obtain glucose concentrations of 50, 100, 200 and 400 mg/dl in each of the four 100 ml vials respectively.

2.4. 100% glucose injection solution

100 g glucose monohydrate was put in a 100 ml volumetric flask, 50 ml aquadest was added and shaken well to become homogenous and then 100 ml aquadest was added. Filtered and removed to 200 ml vial and sterilized in autoclave at 120°C for 20 minutes.

C. Treatment Schedule

1. Testing extracts

The ethanol extract was treated with various concentrations i.e. 10, 20, 30, 40 and 50 mg/200 g BW (Body Weight).

2. Preliminary testing

Preliminary testing was aimed to get the normal glucose level in the blood of the rat when suffering hyperglycemic condition, after administering a 100 % glucose solution and various concentrations of sappan extracts i.e. 50, 100, 200 and 400 mg/dl by intravenous injection in the tail literal vena (Table 1).

3. Glucose tolerance testing

Glucose tolerance testing had been carried out by administrating 100% glucose solution with a dose of 0.1 g/200 g BW, which was added orally. Each group consisted of six testing animals (rats), The extract of sappan wood was administered by various doses: 10, 20, 30, 40 and 50 mg/200 g BW, respectively and destilated water was used as the negative control (K -), while chlorpropamide 50 mg/200 g BW as the positive control (K +). Blood glucose level in rats was measured 1 hour before to seven hours after the treatment.

Blood was taken via tail venous, centrifuged

Table 1. Preliminary testing of extract in white rats

Control	Glucose level in blood after treatment							
+	+	+	+	+	+	+	+	+
-1	0	1	2	3	4	5	6	7

Note:
-1 = Glucose level in blood when fasting
0 = Glucose level in blood in treatment [glucose, extracts, Negative control (-), positive control (+)]
1 to 7 = Glucose level in blood after treatment

and one drop of blood serum was dropped on glucose strip test and it was let for drying for one minute. Measuring the glucose level was done by Reflolux S (Accutrend GC). The data of blood glucose level was calculated by statistical analysis (ANOVA) by making the correlation curve of glucose level versus period (time). From the curve the "Area Under the Curve 0-7 or AUC0-7 " could be calculated with accuracy for each testing groups of animals (P= <0.05) (Sudjana, 1982).

III. RESULT AND DISCUSSION

The blood glucose level of each testing animal after administering glucose solution (100%) with various doses, i.e. 50, 100, 200, and 400 mg/dl via tail literal venous on hyperglycemic condition were measured and calculated. The results showed that the blood glucose level in testing white rat animals increased with the increase of the doses. The blood glucose level on testing animals increased to 49; 103.83; 196.50 and 374.70 mg/dl, respectively (Table 2). Hyperglycemia conditions of the blood of white rats was most striking when given 100% glucose solution at a dose of 400 mg/dl, the average increase in glucose level was 7 times higher than with 50 mg/dl.

The results of the determination of the time interval of hyperglycemic condition in rat (mg/dl) showed the different blood glucose level in testing animals. The average blood glucose level was 145 mg/dl. The hyperglycemic condition was reached in 3 hours after the treatment (Table 3).

It appears glucose tolerance by administering 100% glucose solution at a dose of 0.1 g/200 g BW intravenously. Rats increased blood glucose levels and hyperglycemic conditions occur. Blood glucose tolerance also occured after treatment of the extract that is 10, 20, 30, 40, and 50 mg/200 g BW. Observations during the 4-6 hours after treatment, the rats were in hyperglycemic conditions, but the average blood glucose adapt to the normal condition.

Differences were seen in the rats between control (-1) and fasting conditions given aquadest added with chlorpropamide drugs 50mg/200 gr body weight (Table 3). The time interval required was 2-3 hours for adjustment after the food was absorbed (ingestion) by administering 100% glucose solution. After that time the blood glucose levels rose from an average of (114-117) mg/dl when fasting to (137-152) mg/dl at the time of hyperglycemic. The condition of blood glucose after extract treatment and when anti-diabetic drugs

Table 2. Preliminary recovery of glucose level in blood of testing animals by Reflolux

No	Glucose level (mg/dl)			
	50	100	200	400
1	47	100	208	387
2	57	104	166	362
3	50	114	199	368
4	48	99	203	373
5	49	103	189	376
6	47	106	194	382
Average	49	103.83	196.50	374.70
SD	2.08	5.55	7.67	8.32
Recovery (%)	98.00	103.83	98.25	93.68
CV (5)	5.70	5.34	3.90	2.22

Note : SD = Standard deviation, CV = Coeficient of variation, N= 3

Table 3. Determination of the time interval of hyperglycemic condition in rat (mg/dl)

Periods (hours)	Groups			Average
	1	2	3	
-1	114	117	117	116a
0	124	137	129	130ab
1	130	140	135	135b
2	137	144	142	141bc
3	138	152	145	145c
4	121	132	128	127ab
5	113	127	120	120a
6	108	120	114	114a
7	105	115	110	110a

Note: The average value followed by the same letters were not significantly different

chlorpropamide was added, dropped to an average of (124-137) mg/dl

The results of the average blood glucose level in testing animals after treatment (in mg/dl) gave different levels it depended on the doses of the extracts. There was a difference in the blood glucose level in hyperglycemic conditions between control groups and fasting groups (-1) and extract treatment groups. Negative control groups showed an average blood glucose level of 145 mg/dl three hours after treatment and groups II to VI (extract 10-50 mg/200 g BW) showed a decrease of the blood glucose level to 100- 137 mg/dl, while the level of the positive control was 102 mg/dl. Those results showed that treatment of ethanol extract of sappan wood by administer doses gave a remarkable effect on blood glucose level in rat and also reduced the glucose level in blood compared to negative control and positive control. Treatment with a dose of 30 mg/200 g BW (103 mg/dl) gave a similar effect as the positive control (102 mg/dl), while a dose of 50 mg/200 g BW gave lower blood glucose level (93 mg/dl) than the positive control.

Statistical analysis of those results gave significant differences in all treatments between blood glucose level of administered extract doses versus period (P = < 0.05) (Figure 1). Treatments of doses 20 – 50 mg/200 BW also gave the anti-diuretic effect on testing animals. The research showed that the administered dose of 30 mg/200 g BW of the ethanol extract equals the positive control.

The mechanism of ethanol extract of sappan wood in decreased blood glucose level could be explained as follows:

1. Fructose-2, 6-bisphosphate (F-2, 6-BP), a gluconeogenic intermediate, plays a critical role in hepatic glucose output by regulating gluconeogenesis and glycolysis in the liver. Increased hepatic glucose output is one of the major mechanisms of hyperglycemia in diabetic animal patients.
2. Brazilin, an active component of sappan, decreases blood glucose in diabetic white rat animals

In this study, the effect of brazilin on gluconeogenic intermediate production and enzyme activity were examined to investigate the hypoglycemic mechanism of brazilin. As said by You et al. (2005) brazilin has increased the production of F-2,6-BP in hepatocytes by elevating intracellular levels of fructose-6-phosphate (F-6-P) and hexose-6-phosphate (H-6-P) to enhance insulin receptor function and lower blood sugar.

As reference, Jafri, et.al. (2000) reported that the oral administration of *Punica granatum* L., flower aqueous-ethanolic (50%, v:v) extract led to significant blood glucose lowering effect in normal, glucose-fed hyperglycemic and alloxan-induced diabetic rats. This effect of the extract reached maximum at 400 mg/kg B.W.

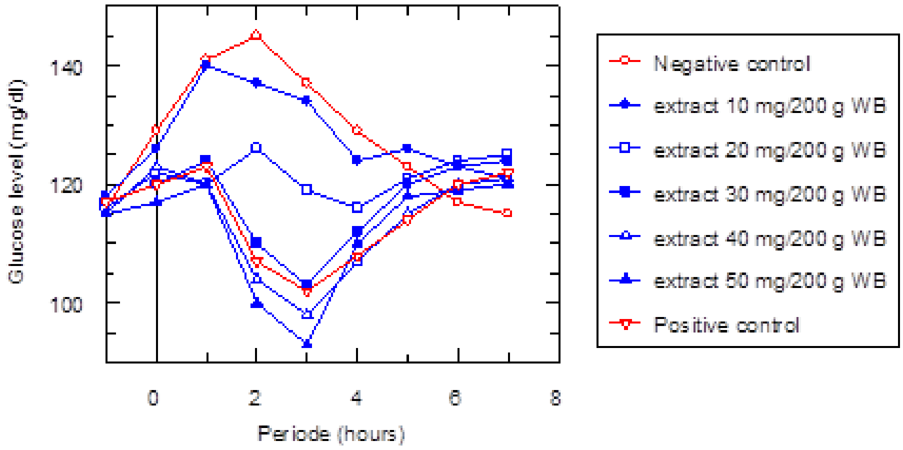

Figure 1. Curve of glucose level in rat blood after treatment

IV. CONCLUSION

This experiment showed that all of the treatment doses decreased the blood glucose level. The treatment of ethanol extract of sappan wood by administering doses gave remarkable effect of blood glucose level in white rats and also reduced glucose level in blood compared to negative control and positive control.

Treatment of dose 30 mg/200 g BW (103 mg/dl) gave similar effect to positive control (102 mg/dl), while dose of 50 mg/200 g BW gave lower blood glucose level (93 mg/dl) than positive control.

As the base material for a standard preparation of fitofarmaka, its effectiveness needs to be advancely tested for quality, safety and efficacy. Further scientific research is still needed to obtain a practical and an effective drug dosage form.

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THE EFFECT OF SILVICULTURAL TREATMENT ON STAND GROWTH OF LOGGED-OVER FOREST IN SOUTH PAPUA

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ABSTRACT

Forest stand structure could be used as one of the variables in deciding the possibility to harvest forest product. On logged-over forests, data and information over stand structure could become the basis for decision making for harvesting. To measure and analyze yield on logged-over forest, each forest management unit (IUPHHK) is obligated to establish Permanent Sample Plots (PSPs) for monitoring the growth and yield of the managed stand. In some of the plots, maintenances and thinning treatments are applied while other plots are not treated. The results, after several years of observations, showed that there was a difference in stand structure (tree number) of each diameter class both in plots with treatment and without treatment. The rate of in-growth, up-growth and mortality varied between plots without and with treatment in each diameter class and length of time after harvesting. The average diameter increment of trees in the stands of the untreated plots was higher (0.60 cm yr^{-1}) compared to the treated plots (0.55 cm yr^{-1}).

Keywords: Structure of stands, logged-over forests, natural forests, increment

ABSTRAK

Kondisi tegakan hutan dapat digunakan sebagai salah satu indicator dalam menentukan adanya kemungkinan untuk penentuan penebangan pada hutan bekas tebangan. Hal ini dapat dilakukan dengan menganalisis kondisi tegakan tersebut dengan menggunakan data dari pengukuran periodic yang dilakukan pada petak ukur permanen (PUP). Pendirian PUP dilakukan oleh pemegang IUPHHK dengan tujuan untuk monitoring pertumbuhan tegakan setelah penebangan. Penelitian ini dilakukan dengan menggunakan PUP yang dilakukan perlakuan penjarangan dan PUP yang tidak ada perlakuan silvikultur (control). Hasil penelitian menunjukan bahwa setelah penebangan, terdapat perbedaan struktur tegakan pada kedua tipe PUP tersebut dalam hal in-growth, up-growth dan mortality. Selanjutnya pada pertumbuhan tegakan pada PUP tanpa perlakuan lebih tinggi yaitu 0,60 cm per tahun, sedangkan untuk tegakan pada PUP perlakuan adalah 0,55 cm per tahun.

Kata kunci: Struktur tegakan, hutan bekas tebangan, hutan alam, riap

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I. INTRODUCTION

Forest management practice (e.g. logging) will provide the ecological impact of changes in the composition and structure of the residual stand in the logged-over forest. Information about the structure of the stand is considered important because in terms of economic factors, the structure of the stand will determine the minimum standing stock of the timber that must be available for good growth, while in terms of ecological factors, the structure of the stand can give an idea about the ability of the stand to regenerate (Suhendang, 1994). Changes in forest stand structure or growth of stand can be affected by external and internal factors, such as climate, soil fertility, pest-diseases as well as genetic origin of trees.

Some important components of the stand growth are ingrowth, upgrowth, and mortality. Ingrowth is defined as trees that grow to a class or stage of growth of the smallest diameter measured during a certain time. Upgrowth is defined as trees that grow to the next diameter class, and mortality is defined as trees that have died within a period of time. Although the mortality reduces the tree basal area of the stand, but the larger growing space will increase the growth of the trees of the residual stand (Buongiorno and Michie, 1980; Golley, 1983; Waring and Schlesinger, 1985; Davis and Johnson, 1987).

To monitor the dynamic of standing stock and stand growth of the logged-over forests, permanent sample plots (PSPs) have to be established in each forest management unit (e.g. forest concessions or logging companies) as stated in the Minister of Forestry Decree No.237/Kpts-II/1995. Therefore, data collected from PSPs providing temporal data of how remaining stands respond after harvesting. The remaining stands can grow naturally faster or slower depending on the growth rate and its response to canopy openness resulting from logging activity. Lal (1960) stated that growth of the remaining stand can be influenced positively by implementing silvicultural treatments. A study conducted by Krisnawati and Wahjono (2010) in logged-over forests in West Kalimantan has shown that growth rate of the remaining stands increased two folds with silvicultural treatment compared to growth rate of the remaining stands without silvicultural treatment.

In logged-over forests in Papua, some PSPs have been established by logging companies. However, there is no complete information in relation to how remaining stands respond to silvicultural treatment in logged-over forest in Papua. This study aims to examine the effect of silvicultural treatments on stand growth of logged-over forests in South Papua.

II. MATERIAL AND METHOD

A. Research Sites

The experiment was conducted on the PSPs series located in the IUPHHK of PT. Tunas Sawaerma, Boven Digul District, Papua Province (Figure 1). Size of each PSP is 100 x 100 m. The PSPs are located in logged-over forest, i.e. Annual Work Plan (RKT) Block of 2004, Five-yearly Work Plan (RKL) Block IV of 2004 to 2009, and Logging Block E 55. The topography is relatively flat to undulating with a slope of 0-8% and elevation of 20-50 m above sea level (a.s.l). Soil types found in the second area are ultisol, gray brown podzolic, red yellow podzolic and alluvial. The climate is classified as type A with an average annual rainfall of 4196 mm. Number of rainy days per month ranges between 11 and 24 days.

B. Material

The material used in this study was measurement data from six PSPs established in logged-over forest of PT. Tunas Sawaerma which have been annually measured from 2005 to 2011.The measurements were conducted for all trees growing in PSPs which had a diameter at breast height (DBH) of 10 cm or larger. Silvicultural treatment was applied in PSP 1, PSP 2 and PSP 3 by cutting trees with DBH below 10 cm and lianas around future crop

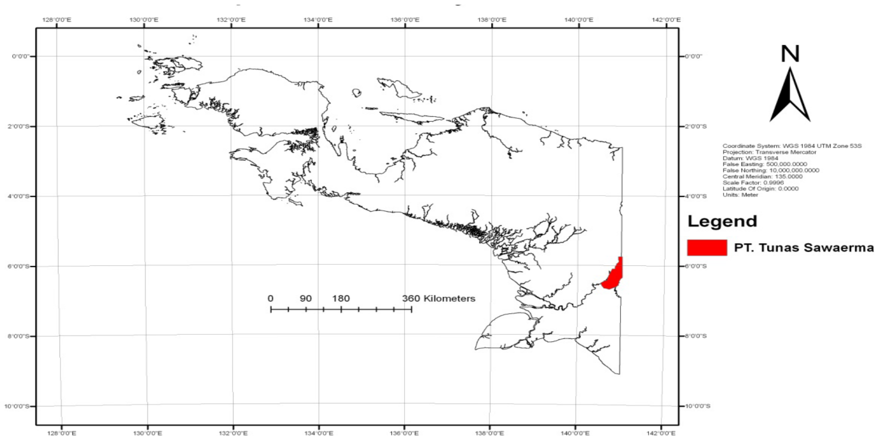


Figure 1. Map of the study area of PT. Tunas Sawaerma, Boven Digul

trees; while PSP 4, PSP 5 and PSP 6 were as control plots with no silvicultural treatment.

C. Data Processing

Diameter of the trees in the plots was grouped using 10 cm intervals as diameter classes from 10 cm to 50 cm. In each plot, ingrowth, upgrowth, mortality and diameter increment of stands were analyzed by diameter class. The calculations were as follow:

1. **Ingrowth**

   Ingrowth is defined as the proportion of new trees growing to the smallest diameter class (10-19 cm). The ingrowth rate was calculated by the following formula :

   where I : Ingrowth rate; ri : Number of new trees growing to the smallest diameter

$$I = \frac{\sum r_i}{\sum N_i} x100\% \quad \text{.................................(1)}$$

   class at year i; and N_i : Number of trees in the smallest diameter class at year i.

2. **Upgrowth**

   Upgrowth is defined as the proportion of trees that grow up to the next larger diameter class. Upgrowth rate was calculated by the following formula:

   where U_i : upgrowth rate of the diameter class i; u_{ij} : Number of trees growing to the

$$U_i = \frac{\sum u_j}{\sum N_j} x100\% \quad \text{.................................(2)}$$

   next diameter class at year i; N_{ij} : Number of trees in diameter class iat year j

3. **Mortality**

   Mortality is defined as the proportion of dead trees within the measurement period. The mortality rate was calculated by the following formula:

   where M_i : Mortality rate for diameter class i; u_{ij} : Number of died trees in diameter class

$$M_i = \frac{\sum m_j}{\sum N_j} x100\% \quad \text{.................................(3)}$$

   i at year j ; N_{ij} : Number of trees in diameter class i at year j

4. **Increment**

   Current Annual Increment (CAI) of diameter was calculated by the following formula:

$$CAI = D_{t+1} - D_t \quad \text{...(4)}$$

   where : D_t = diameter at year t, t = year of measurement.

D. Data Analysis

A stand structure model was developed for each year of measurement. The model used is the stand structure model developed by Meyer (1952):

$$N_t = N_o e^{-kD} \quad \text{...(5)}$$

where N_t : Number of trees per ha per diameter class; D : Diameter; k : constant; N_o : Number of trees in the smallest diameter class; and e : natural logarithm.

III. RESULT AND DISCUSSION

A. Stand Structures

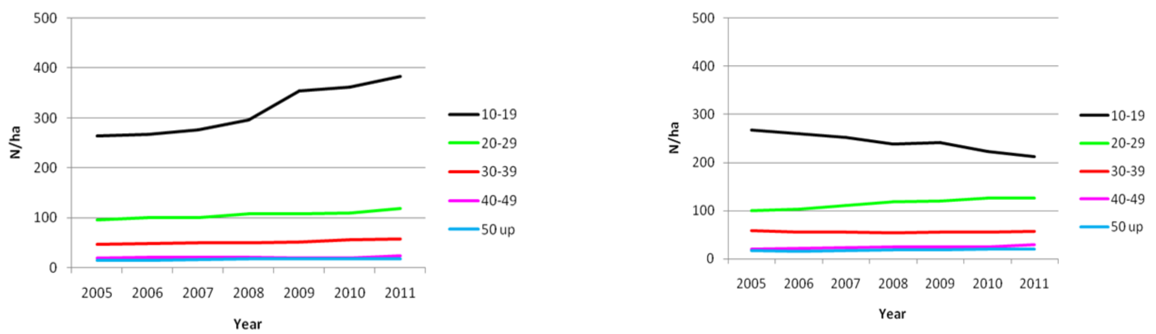
Stands in PSPs with or without treatment are growing in more or less in the same abiotic condition as mentioned in the previous part. Therefore, variation of stand structures in this study was expected as result of variation of diameter class, silvicultural treatment as well as time.

The stand structure is, furthermore, the physical and temporal distribution of trees in stands by type, vertical and horizontal distribution patterns, size of the trees, including canopy volume, leaf area index, stem, stem cross section, age of a tree or a combination of these (Oliver and Larson, 1990). Since the age of the stand is unknown and cannot be determined precisely in natural forest, then the diameter distribution of the trees per hectare can be used to explain the stages of tree growth (Meyer et al., 1961).

The number of trees per diameter class from each PSP (both with and without treatment) after a few years of measurement is presented in Figure 2.

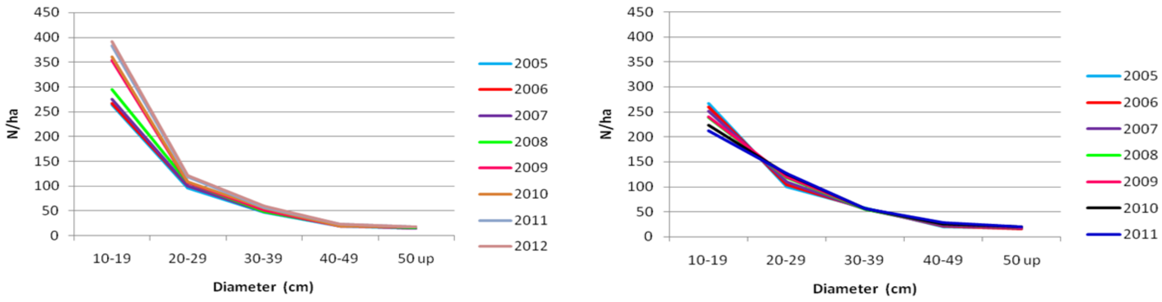
Figure 2 shows that there are differences in the number of trees per PSPs without and with treatment after several years of measurements based on the diameter class of the stand. In the diameter class of 10-19 cm, the number of trees in PSPs without treatment increased with time, but on the other hand, it has decreased on the PSPs with treatment. The decrease is a result of liberation treatment in these PSPs. The liberation was done by cleaning small trees and liana around future trees. Intensity of liberation was high in which 75 % of small trees and liana was cleaned in this treatment. Small trees of commercial species in the plot could not actually compete with other species that were not commercial species. Therefore, only a few number of small trees entered in the smallest diameter class (10-19 cm). Then, it predictably resulted in slow growth and high mortality of small trees causing low ingrowth as presented in Figure 2 (b).

In contrast, the number of trees with DBH above 20 cm in PSPs both with and without treatment increased every year. The increase of PSPs with treatment was higher than the increase of PSPs without treatment. The higher increase was in consequence of higher ingrowth of future trees because liberation has reduced competition between future trees and



(a) (b)

Figure 2. Number of trees per hectare based on diameter classes in PSPs: (a) PSPs without treatment (b) PSPs with treatment



(a) (b)

Figure 3. The stand structure of PSPs:(a) without treatment (b) with treatment

Table 1. Stand structure model of PSPs (with and without treatments) after several years of measurements

Time of Measurement After cutting	PSPs without treatment		PSPs with treatment	
	Model of stand structure	R^2(%)	Model of stand structure	R^2(%)
t + 1	$N = 462.9e^{-0.73D}$	97.0	$N = 475.2e^{-0.71D}$	96.4
t + 2	$N = 474.8e^{-0.73D}$	97.7	$N = 469.4e^{-0.71D}$	97.6
t + 3	$N = 485.1e^{-0.73D}$	97.3	$N = 462.3e^{-0.69D}$	98.4
t + 4	$N = 509.3e^{-0.73D}$	96.1	$N = 433.0e^{-0.66D}$	98.3
t + 5	$N = 584.8e^{-0.76D}$	94.3	$N = 439.6e^{-0.66D}$	98.1
t + 6	$N = 604.2e^{-0.76D}$	94.5	$N = 416.3e^{-0.64D}$	97.9
t + 7	$N = 664.7e^{-0.78D}$	96.6	$N = 392.7e^{-0.61D}$	98.6

small trees. As a result, the future trees were not suppressed when they were growing.

The average stand structure of PSPs with and without treatment during several years of measurements can be seen in Figure 3.

Based on the form of stand structure, stand structure curves can be generated by using the negative exponential equation as shown in Table 1.

Table 1 shows that the general model of forest stand structure on PSPs follows the model of natural forest's stand structure, that is the reversed-J shape. Thus, the number of trees decreases with increasing diameter, in both PSPs with and without treatment. However, the specific form of the reversed-J shape, i.e. the steepness can vary from one stand to another. Steepness depends on the diameter class distribution and the smallest and largest number of trees in each diameter class (Meyer et al., 1961; Davis and Jonson, 1987). The position of the curve on the abscissa is associated with the largest-diameter trees; density of residual stand determines the position of the curve between the axes, and the slope of the curve is determined by the distribution of the diameter classes (Marsono, 1987). The suitability of the natural forest stand structure model is confirmed by the high significance (R2) level ranging from 94.3% to 97.7% on the PSPs without treatment and 96.4% to 98.6% on the PSPs with treatment. Thus the stand structure model $N = N_0 e^{-kD}$ is acceptable for both PSPs without treatment and with treatment at each measurement time.

B. Stand Growth

Stand growth is the change in the size such as diameter and height of stands that occur during a specific time period. In forest management, the stand growth can be also expressed as increment in terms of stand volume ($m^3ha^{-1}year^{-1}$) which is used to show the maximum amount of timber volume that

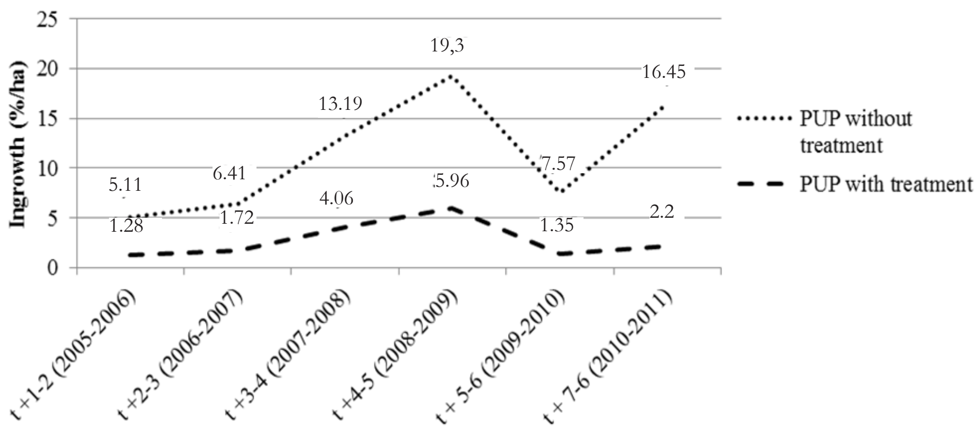


Figure 4. Ingrowth rate of PSPs without treatment and PSPs with treatment

can be harvested in the period (year) or better known as annual allowable cut (AAC) (David and Jonson, 1987; Vanclay, 1995).In this study, we present ingrowth, upgrowth, and mortality as driving factors which contribute to the stand growth.

1. Ingrowth

The rate of ingrowth in both PSPs without and with treatment can be seen in Figure 4. Figure 4 shows that the rate of ingrowth was higher in PSPs without treatment in all years of observation. This is caused by the high intensity of treatment applied early to the PSPs with treatment resulting in significantly reduced number of trees with diameter below 10 cm which led to a small number of recruited trees in the plots.

In general, ingrowth of both PSPs with and without treatment increases several years after logging. It can be seen that the highest rate of ingrowth occurred in the fifth year on the PSPs either without treatment (19.30%) and on PSPs with treatment (5.96%). Increase of ingrowth in this logged-over forest is owing to more gap in the canopy, which stimulates more light reaching the understory. In addition, micro-climatic circumstance is recovering after several years, which influence small trees to grow faster (Golley, 1983).

With the increasing stand density, basal area will increase and ingrowth rate may drop in subsequent years due to competition between trees.

2. Upgrowth

Upgrowth pace during several years of observations in PSPs can be seen in Figure 5. Figure 5 shows that the rate of upgrowth in the diameter classes vary from each time of the observation as well as between PSPs. The highest rate of upgrowth was in diameter class 40-49 cm both in PSPs without and with treatment. The rate of upgrowth in plots without treatment tended to increase with time after cutting in all diameter classes except in the diameter class ≥ 50 cm which tended to decline. This means upgrowth is higher with increasing number of trees (stand density) (Buongiorno and Michie, 1980; Buongiorno et al, 1995; Kofod, 1982; Oliver and Larson, 1990).This condition explains the phenomenon of growth in logged-over forest. Gap of canopy after harvesting stimulates the tree growth thereby increasing the density of the stands (Davis and Johnson, 1987). Moreover, trees compete with other trees in order to be dominant trees so the trees can receive more light (Folley, 1983).

In the PSPs with treatment, there was a fluctuation of upgrowth rate in all classes. The highest upgrowth appeared in the fourth year after cutting in all diameter classes, and then declined, but tended to increase again in the following years. This is in line with the reduction in the number of trees (stand density). Upgrowth varied in each diameter

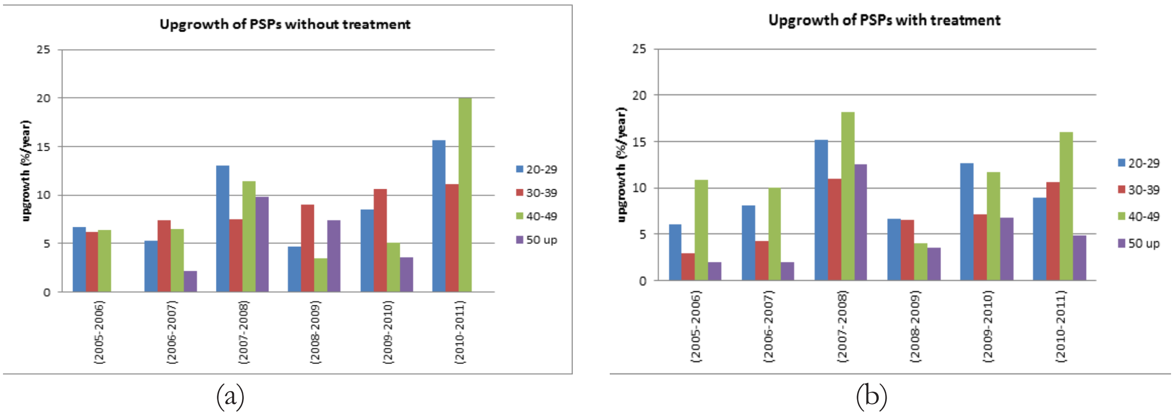


Figure 5. The rate of upgrowth in PSPs (a) without treatment (b) with treatment

Table 2. Mortality rate of PSPs without and with treatment based on diameter classes

Diameter Class (cm)	PSPs without treatment (%)					
	$t_{+1\text{-}2}$ (2005-2006)	$t_{+2\text{-}3}$ (2006-2007)	$t_{+3\text{-}4}$ (2007-2008)	$t_{+4\text{-}5}$ (2008-2009)	$t_{+5\text{-}6}$ (2009-2010)	$t_{+6\text{-}7}$ (2010-2011)
10 – 19	1.5	1.3	1.7	0.9	1.4	2.4
20 – 29	0.0	2.0	2.2	0.3	1.2	2.5
30 – 39	1.4	2.7	4.8	1.3	1.2	2.4
40 – 49	0.0	6.6	3.3	1.7	0.0	5.7
≥ 50	0.0	0.0	0.0	1.9	1.8	5.8
	PSPs with treatment (%)					
Diameter Class (cm)	$t_{+1\text{-}2}$ (2005-2006)	$t_{+2\text{-}3}$ (2006-2007)	$t_{+3\text{-}4}$ (2007-2008)	$t_{+4\text{-}5}$ (2008-2009)	$t_{+5\text{-}6}$ (2009-2010)	$t_{+6\text{-}7}$ (2010-2011)
10 - 19	1.8	0.8	2.4	1.7	2.3	1.9
10 - 29	1.0	1.5	2.8	2.5	4.8	3.4
30 - 39	2.4	1.2	2.5	1.8	2.4	1.2
40 - 49	1.6	0.0	2.6	4.0	2.6	1.2
≥50	4.1	0.0	1.8	1.8	3.4	1.64

class both in PSPs with treatment and in PSPs without treatment as shown proportionally in Figure 5.

3. Mortality

Magnitude of the rate of mortality in PSPs without treatment and PSPs with treatment can be seen in Table 2. Table 2 above shows that the rate of mortality varied in the diameter class, with the time between the observation and treatment. In PSPs without treatment the highest mortality rate occurred in diameter class 40-49 cm in the third year after logging, it was 6.6% and then decreased in the following year and then rose in the eighth year by 5.7%. Mortality rate of trees with diameter ≥ 50 cm tended to increase in line with the length of the time after harvesting. This was a result of logging and skidding which moderately damaged the canopy, trunks and buttress of the tree. In the PSPs with treatment the highest mortality rate occurred in diameter class 20-30 cm which was 4.8%.The diameter class has increased in mortality rate in line with the length of time after logging. This difference is caused by differences in response to the disturbances caused by the logging (Golley, 1983). Extreme changes in micro-climatic conditions after logging and the damage caused by logging affected the young trees more so that the small size trees die relatively faster than trees with larger diameter (Golley, 1983; Schulte, 1996; Waring and Schlesinger, 1985). The diversity of the high mortality may also not be separated from the fact that the death

Table 3. Average current annual increment (CAI) in various diameter classes

Class Diameter	Plot PSPs without treatment						
	t_{+1-2} (2005-2006)	t_{+2-3} (2006-2007)	t_{+3-4} (2007-2008)	t_{+4-5} (2008-2009)	t_{+5-6} (2009-2010)	t_{+6-7} (2010-2011)	Average
10 – 19	0.41	0.52	0.80	0.59	0.73	0.85	0.65
20 – 29	0.37	0.39	0.84	0.46	0.56	0.76	0.56
30 – 39	0.43	0.36	0.99	0.41	0.50	0.84	0.59
40 – 49	0.40	0.46	0.89	0.52	0.62	0.74	0.60
≥ 50	0.48	0.37	0.89	0.51	0.51	0.89	0.61
Average	0.42	0.42	0.88	0.50	0.58	0.81	0.60

Class Diameter	Plot PSPs with treatment						
	t_{+1-2} (2005-2006)	t_{+2-3} (2006-2007)	t_{+3-4} (2007-2008)	t_{+4-5} (2008-2009)	t_{+5-6} (2009-2010)	t_{+6-7} (2010-2011)	Average
10 - 19	0.40	0.42	0.69	0.40	0.56	0.63	0.52
20 - 29	0.38	0.39	0.85	0.39	0.67	0.75	0.57
30 - 39	0.39	0.41	0.90	0.45	0.67	0.80	0.60
40 - 49	0.51	0.29	0.79	0.36	0.50	0.71	0.53
≥50	0.40	0.39	0.78	0.46	0.64	0.68	0.56
Average	0.42	0.38	0.80	0.41	0.61	0.72	0.55

of trees in a stand is a process that is complex and relatively difficult to predict because of the many interacting factors (Waring, 1987).

C. Stand Increment

Diameter increment is one important component that determines the increment in volume. The stand increment depending on diameter and height growth. In this study, we used Current Annual Increment (CAI), Periodic Annual Increment (PAI), and Mean Annual Increment (MAI). CAI is the increment in the current year, the PAI is the increment in one time period while the MAI is the increment on average (per year) that occurs during a certain time period (Prodan, 1968).

The average Current Annual Increment (CAI) on PSPs without and with treatment after several years of measurement can be seen in Table 3. Table 3 shows that there is a difference in the CAI of diameters in both PSPs without and with treatments. In PSPs without treatment, the highest CAI was in the diameter class10-19 cm (equal to 0.65 cm per year). This is caused by high ingrowth of pioneer species. In addition, gap in the canopy due to felling of trees encouraged the growth of small trees while on the PSPs with treatment the highest CAI was in the diameter class 30-39 cm (0.60 cm per year).The highest CAI in the diameter class 30-39 was due to open space resulting from logging.

Average current annual increment (CAI) on PSPs without treatment was higher than on PSPs with treatment. The low CAI on PSPs with intensive treatment was caused by the treatment given to cleaning off the stand diameter <10 cm. Besides, caused by the density of stands, the higher CAI in PSPs without treatment is owing to differences in type and environmental conditions. Tree growth is largely determined by the interaction of three factors: heredity, environment and silvicultural techniques (Kramer and Koslowski, 1960). Lal (1960) mentioned that the factors that influence the size of the increment of a stand is an act of silviculture, type and quality of place to grow. The external factors like edaphic and climatic conditions also influence the growth of the stand. Undaharta et al. (2008) mentioned that the stand increment is also influenced by stand density, soil type and fertility. The stand increment of a tree can be seen from the speed of growth (Simon, 2007).The growth rate of young trees is generally higher and when they are mature the growth rate will reach a plateau at one time.

IV. CONCLUSION

A. Conclusion

Stand structure indicates that there was a difference between PSPs without and with treatment in each diameter class. General model of stand structure can be used to determine the shape of the stand structure of PSPs without and with treatment.

Growth of a stand is affected by the components of the growth, i.e. ingrowth, upgrowth and mortality. The rate of ingrowth, upgrowth and mortality varies between PSPs without and with treatment in each diameter class and length of time after harvesting.

Average annual diameter increment of trees on PSPs with treatment was 0.55 cm yr^{-1}, which is relatively slower than PSPs without treatment, where it was 0.60 cm yr^{-1}. It was affected by the type of silvicultural and environmental actions.

B. Recommendation

Future research related to the increment of the same species is required to produce a growth model, taking into account existing environmental factors.

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VARIATION IN BIOFUEL POTENTIAL OF TWELVE *Calophyllum inophyllum* POPULATIONS IN INDONESIA

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ABSTRACT

The global energy crisis has raises demand for biofuel prices. It has driven the world to enhance environmentally-friendly renewable-energy (biofuel) production. Oil from the seeds of *Calophyllum inophyllum* (nyamplung) which can be harvested up to 50 years, is one of such potential biofuel source. Methods for biofuel production from nyamplung seeds have been developed at an industrial scale by cooperative in Cilacap (Java) and Energy Self-Sufficient Villages (*Desa Mandiri Energi*) in Banyuwangi, Purworejo, Kebumen, Ujung Kulon (Java) and Selayar (South Sulawesi). However, there is only a limited-information available on biofuel potential, in term of productivity and quality, from nyamplung populations. This paper reports the variations in biofuel potential among 12 populations in Indonesia (6 from Java, 6 outside Java). The oil was extracted using a combination of vertical hot press (VHP) and screw press expeller (SPE) methods, followed by degumming to make refined oil, and esterification-transesterification to turn it into biodiesel. The result show great variation of biofuel content among the population. Oil production percentage varies from 37-48.5% (VHP) and 50-58% (SPE) crude oil, 36-48% (VHP) and 40-53% (SPE) refined oil, and 17-33% (SPE) for biodiesel. Seed resin content is responsible for most of the variation after degumming. DNA analysis shows genetic variation among populations ranges from intermediate within Java to high ouside Java and is intermediate within populations. Information about biofuel content and potential of populations and genetic variation between and within population are important factors for establishment of genetically-improved seed-sources for biofuel production from nyamplung.

Keywords: Biofuel, crude oil, genetic-variation, nyamplung (*Calophyllum inophyllum*)

ABSTRAK

Krisis energi mendorong penduduk dunia untuk mengalihkan sumber energinya ke energi terbarukan (biofuel) yang lebih ramah lingkungan. Nyamplung (*Calophyllum inophyllum*) sebagai salah satu jenis tanaman hutan mempunyai potensi sebagai bahan baku biofuel dari bijinya dan dapat berproduksi sampai dengan umur 50 tahun. Secara teknis pemanfaatan biji nyamplung sebagai biofuel tidak menjadi masalah dan sudah mulai dikembangkan dalam skala industri oleh Koperasi Jarak Lestari di Cilacap (Jawa Tengah) dan melalui program Desa Mandiri Energi (DME) berbasis nyamplung di Banyuwangi (Jawa Timur), Purworejo dan Kebumen (Jawa Tengah), Ujung Kulon (Banten), dan Selayar (Sulawesi Selatan). Namun demikian, ketersediaan dan kualitas bahan baku dari biji nyamplung menjadi kendala utama karena belum tersedia informasi produktivitas minyak yang optimal. Tulisan ini menyajikan variasi potensi biofuel nyamplung dari 12 (dua belas) populasi nyamplung di Indonesia (6 populasi di Jawa dan 6 populasi di luar Jawa) untuk membangun sumber benih unggul nyamplung. Rendemen minyak dihasilkan dengan menggunakan kombinasi alat *Vertical Hot Press* (VHP) dan *Screw Press Expeller* (SPE) dilanjutkan dengan proses degumming untuk menghasilkan refined oil dan proses esterifikasi-transesterifikasi untuk menghasilkan biodiesel. Hasil penelitian menunjukkan terdapat variasi yang cukup tinggi diantara populasi nyamplung di Indonesia

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terhadap rendemen biofuel. Persentase rendemen minyak bervariasi antara 37-48,5% dengan VHP dan 50-58% dengan SPE untuk crude oil, 36-48% (VHP) dan 40-53% (SPE) refined oil, dan 17-33% (SPE) untuk biodiesel. Variasi tertinggi ditunjukkan pada rendemen biofuel setelah degumming karena biji nyamplung mengandung getah yang cukup tinggi. Analisa DNA menunjukkan variasi genetik antar populasi bervariasi dari sedang untuk populasi di Jawa sampai dengan tinggi untuk populasi di luar Jawa. Informasi rendemen biofuel dan potensi dari populasi nyamplung serta variasi genetik antar populasi dan didalam populasi menjadi faktor penting untuk pembangunan sumber benih unggul untuk produksi biofuel nyamplung.

Kata kunci: Biofuel, minyak mentah, nyamplung (*Calophyllum inophyllum*), variasi genetik

I. INTRODUCTION

Biofuel demand and prices are affected by the global energy crises. It has been the crucial reason for the world to urgently look for renewable-energy (biofuel) sources that are environmentally friendly. Biofuel is one of the many alternative forms of energy (Hayes et al., 2007). In this context, the Indonesian government through the national energy policy has set biofuel production target to contribute by 5% of the national energy needs in 2025. The Ministry of Forestry was assigned to play an important role in providing biofuel raw materials and to give explicit licence for the use of unproductive forest lands for further biofuel development (ESDM, 2006).

In general, there is no crucial constraint in the technology of the biofuel process. However, more research on increasing its efficiency is required for making it feasible at operational scale. The main restraints are raw material availability, quality and strong competition from the food sector, in the context of food security. Currently, biofuel production is obtained primarily from food sources such as oil palm, coconut, cassava, corn, sorghum and other sources of carbohydrats. Non-edible biofuel sources such as jatropha that has previously been introduced in Indonesia, have their own problems with limited seed productivity resulting in production inefficiencies and land use competition for food purposes. Provision of non-edible plant sources of biofuel that do not pose significant threats to farmlands is therefore critical.

The seeds of *Calophyllum inophyllum* (common name: nyamplung) have long been used for biofuel; therefore it is one of the potential tree species for energy sources (Soeryawidjaja, 2005; Sopamena, 2007). The seeds can be harvested repeatedly from a nyamplung tree until the tree is 50 years old. In its natural habitat, nyamplung grows along the coast line which less interference with food production. Nyamplung has been grown in Indonesia as wind break along marginal coastal areas and planted on unproductive lands for 50 years. Nyamplung seed production reachs 40-150 kg/tree/year corresponding to 20 ton/ha/year exceeding the seed production of other species for similar pupose such as jatropha (5 ton/ha/year) and oil palm (6 ton/ha/year) (Bustomi et al., 2008).

Commercially, biofuel of nyamplung has been produced intensively by Jarak Lestari Cooperation in Cilacap (Java) and Energy Self-Sufficient Villages (Desa Mandiri Energi) in Banyuwangi, Purworejo, Kebumen, Ujung Kulon (Java) and Selayar (South Sulawesi) (Dephut, 2008; ESDM, 2006, 2007, 2008). Biofuel from nyamplung can substitute fossil fuels. The foremost obstacle for nyamplung-based bioenergy to production is the limitation of nyamplung seeds as raw materials. Reliance on raw materials from unselected natural or planted stands and the lack of improved nyamplung seeds have been suggested as the causes of inconsistency in nyamplung oil production and quality. Strategic breeding is one possible solution to enhance nyamplung oil quality (Leksono and Widyatmoko, 2010).

It started with identification of initial stand potential and land properties within and between 6 nyamplung population from Java (Leksono et al., 2010) and from 6 population outside Java (Leksono, 2011).

The high level of phenotypic variation among populations led to the necessity to undertake studies on examining oil potential and charactersistic within each population and among nyamplung population in Indonesia. This information is essential for assessing the potential of nyamplung forest plantations in Indonesia to support biofuel program and the benefits that would results from genetic improvement. With regard to those purposes research here was conducted to analyze biofuel characteristics of nyamplung from each population and to provide information on variation in biofuel production and quality, including content of crude oil, refined oil and biodiesel.

II. MATERIAL AND METHOD

A. Time and Location

This study comprising collecting genetic materials (seeds) and analyses of nyamplung biofuel (Crude Oil, Refined Oil, and Biodiesel), was conducted during 2009-2012. Materials were collected from 12 nyamplung populations (provenances and land races) in Indonesia describe below. The pressing process and analyses of nyamplung biofuel were carried out in several laboratories:

1. Energy and Agro Electrification Laboratory, Faculty of Agricultural Technology, Bogor Agricultural University (IPB) in Bogor, using Vertical Hot Press (VHP) to produce crude oil and refined oil and physical-chemical analyses of crude oil of six populations from Java and two populations from Sumenep (Madura) and Selayar (South Sulawesi).
2. Bioenergy Laboratory, CV. Cahaya Khatulistiwa in Yogyakarta, using Screw Press Expeller (SPE) to produce crude oil, refined oil and biodiesel of seven populations from seven islands (six populations from outside Java and one population from Gunug Kidul (Jogjakarta)).
3. Oil physical character and oil chemical character Laboratories, Research and Development Center for Oil and Gas Technology "LEMIGAS", Ministry of Energy and Mineral Resources, Jakarta, to analyze physical-chemical properties of nyamplung biodiesel from seven populations of seven islands in Gunung Kidul (Jogjakarta), Pariaman (West Sumatra), Ketapang (West Kalimantan), Sumenep (Madura), Dompu (West Nusa Tenggara), Selayar (South Sulawesi), Yapen (Papua).

B. Material and Methods

Biofuel analyses was undertaken using seeds from 12 nyamplung populations in Indonesia represented by six populations (natural and plantations) in Java (Table 1) and 6 populations outside Java (Tabel 2). The fruits were collected from trees and under the trees at each population. Materials for biofuel analyses included lint, H_3PO_4, aquadest, methanol, NaOH, H_2SO_4. Tools and equipments used for carrying out the researche included analytical balance, wooden hammer, fruit and seed cracker, grinder, vertical hot press, screw press expeller, funnel, separating funnel, erlenmeyer, measuring glass, heater and magnetic stirrer.

C. Method

1. Preparation of genetic materials (seeds)

Nyamplung fruits were collected and crushed to separate fruit flesh and shell, followed by further breakage of the shell to release the seeds. Seed samples were dried under the sun for three days to obtain dry seed weight with water content of 8-12%. The fruit and seed sizes of nyamplung and the percentage of seed weight (wet and dry conditions) against fruit weight (dry condition) are presented in Table 3 and Table 4.

Table 1. Environmental conditions of six nyamplung populations in Java

No	Nyamplung population	Geographical positions	Population type	Altitude (masl)	Soil texture	Temp. (°C)	Rainfall (mm/yr)
1.	Banyuwangi (East Java)	08°26'45" South 114°20'16" East	Natural forest, along the coast	0	Sandy	23 - 32	1400
2.	Gunung Kidul (Jogjakarta)	07°53'25" South 110°32'55" East	Plantation, hilly limestone	150	Clayish	21 - 32	1800
3.	Purworejo (Central Java)	07°50'57" South 109°53'42" East	Plantation, along the coast	0	Sandy	23 - 32	1400
4.	Cilacap (Central Java)	07°41'20" South 109°8'35" East	Natural forest, along the coast	5 - 8	Loamy clay	23 - 32	1000
5.	Ciamis (West Java)	07°45'0.23" South 108°30'8.29" East	Natural forest, along the coast	2 - 5	Sandy	23 - 32	3000
6.	Pandeglang (Banten)	06°08'0" South 105°50'0" East	Natural forest, along the coast	0	Sandy clay	19 – 32	3100

Source : Leksono et al. (2010)

Table 2. Environmental conditions of six nyamplung populations outside Java

No	Nyamplung population	Geographical positions	Population type	Altitude (masl)	Soil texture	Temp. (°C)	Rainfall (mm/yr)
1.	Pariaman (West Sumatra)	0°35'39" South 100°06'09" East	Natural forest, along the coast	0	Sandy	23 - 32	2000
2.	Ketapang (West Kalimantan)	01°12'52,20"South 109°55'50.52" East	Natural forest, along the coast	0 - 15	Sandy	25 - 30	2000
3.	Sumenep (Madura)	07°04'31.6" South 113°49'50.1" East	Natural forest, along the coast	2 - 3	Sandy	26 - 29	900
4.	Dompu (West N.Tenggara)	08°17.18'0.2"South 117°59'54.2" East	Natural forest, along the coast	0	Sandy	20 - 32	500
5.	Selayar (South Sulawesi)	06°09'8.2" South 120°30'51.7" East	Natural forest, hilly areas	9 - 35	Clayish	21 - 34	1700
6.	Yapen (Papua)	01°56'04.1" South 136°21'49.4" East	Natural forest, along the coast	0	Sandy	24 - 30	1500

Source : Leksono et al. (2011)

2. Pressing seeds

Currently, there are two equipments used for extracting biofuel from nyamplung seeds; hydraulic press machine and screw press machine (Sudradjad and Hendra, 2012). Nyamplung biofuels from Java populations were assessed using vertical hot press, a hydraulic press technology available at that time. Nyamplung seeds of six populations from Java and three populations from outside Java were collected for pressing using Vertical Hot Press (VHP) method and nyamplung seeds of six populations from Java with one additional population from Gunung Kidul (Jogjakarta) to represent Java populations were collected for pressing using Screw Press Expeller (SPE) method.

3. Degumming process

Degumming is the process of separating oil and gum from Crude Calophyllum Oil (CCO) produce from both methods (VHP and SPE). The method was conducted by diluting with 1% phosphoric acid (H_3PO_4) of the CCO volume

Table 3. Average fruit and seed sizes of nyamplung from six Java populations

Nyamplung Population	Fruit size			Seed size		
	Weight (gram)	Length (cm)	Diameter (cm)	Weight (gram)	Length (cm)	Diameter (cm)
Banyuwangi (East Java)	10.0	3.0	2.8	1.4	1.1	1.1
Gunung Kidul (Jogjakarta)	7.7	2.9	2.5	1.9	2.1	1.5
Purworejo (Central Java)	7.1	2.7	2.5	1.7	1.9	1.5
Cilacap (Central Java)	11.1	3.0	2.8	1.8	2.2	1.5
Ciamis (West Java)	9.0	3.0	2.8	1.9	2.4	1.6
Pandeglang (Banten)	8.7	31	2.7	1.9	2.2	1.6

Source : Leksono et al. (2012)

Table 3. The weight of fruit weight, seed shell, wet seed and dry seed of seven nyamplung populations from 7 islands in Indonesia

No	Nyamplung Populations	FW (Kg)	SS (Kg)	SS/FW (%)	WS (Kg)	WS/FW (%)	DS (Kg)	DS/FW (%)
1.	Gunung Kidul (Jogjakarta)	20	11.5	57.5	8	40	7.3	36.5
2.	Sumenep (Madura)	20	11.0	55.0	7	35	6.0	30
3.	Selayar (South Sulawesi)	20	12.0	60.0	8	40	6.0	30
4.	Padang (West Sumatra)	20	11.0	55.0	7	35	6.0	30
5.	Ketapang (West Kalimantan)	20	12.0	60.0	7	35	6.0	30
6.	Dompu (NTB)	20	11.0	55.0	7	35	6.0	30
7.	Yapen (Papua)	20	11.5	57.5	7	35	6.0	30

Key: FW= fruit weight, SS= seed shell , WS= wet seed, DS= dry seed

into CCO, followed by heating up to 60°C and 30 minute stirring. Green CCO will turn into brownish or yellowish color depending on the characters of the processed nyamplung seeds. After heating, CCO was left for 4-6 hours, so that the gum would be separated at the bottom while the degumming oil would float on the top. The oil was taken as refined oil/refined crude calophyllum oil (RCCO).

4. Esterification-Transesterification-Biodiesel process

Esterification is a reaction process of changing Free Fatty Acid (FFA) into Fatty Acid Methyl Eter (FAME) compounds, a generic name of biodiesel. In this esterification process, oil from degumming (Refined Crude Calophyllum Oil) process was reacted with 20% methanol and 2% H_2SO_4 catalyst of the RCCO volume. The sulfuric acid (H_2SO_4) was mixed into methanol and stirred until it was perfectly dissolved before pouring it into RCCO. It was then heated up to 60-65°C with 2 hour stirring. In this esterification process, the oil will release its acid grease that will stay at the bottom separated from ester oil at the top

Transesterification is a reaction to change triglyceride into FAME compounds. In this process, ester oil was reacted to 20% methanol and 1% NaOH catalyst of the ester oil volume. NaOH was mixed into the methanol and it needed to be perfectly dissolved before pouring it into ester oil. It was then heated up to 60-65°C for 2 hours. Transesterification content was set to separate oil (crude biodiesel) and glycerol.

In producing biodiesel, crude biodiesel (transesterification content) needs to be washed and dried. Washing was carried out by mixing 30% warm water of the crude biodiesel at 50^{o} C into crude biodiesel, with 3 minute stirring. It was then set for 1 hour to separate water, at the bottom and wet biodiesel, at the top. Washing was conducted until the water was clear. Wet biodiesel with high moisture content looks blurry, therefore in order to produce clear transparent biodiesel, the solution was heated up to 90-100^{o}C to evaporate the water content.

Analyses of physical and chemical nyamplung biodiesel was undertaken to assess 18 biodiesel properties as prerequisites for qualified biodiesel. Analyses were carried out by using method of esther alkil biodiesel quality testing according to SNI 04-7182-2006 for biodiesel. Analyses were conducted for each biodiesel from seven nyamplung populations from seven islands in Indonesia.

D. Determination of Biofuel Content

Biofuel analyses of nyamplung was carried out to examine variation in the potential of biofuel from 6 nyamplung populations in Java and 7 island populations in Indonesia (including 1 population from Jawa). The former was conducted to assess the content of crude calophyllum oil (CCO) and refined crude calophyllum oil (RCCO), while the latter was for the CCO, RCCO, and biodiesel. Formula used to calculate these three parameters is as follow:

$$\text{Biofuel content} = \frac{\text{Weight of biofuel extraction}}{\text{Seed weight}} \times 100\%$$

Where:
Biofuel content = content of CCO/RCCO/Biodiesel (%); Weight of biofuel extraction = weight of CCO/ RCCO/Biodiesel (kg); Seed weight = weight of dry nyamplung seeds (kg)

III. RESULT AND DISCUSSION

A. Variation in Biofuel Potential of Nyamplung Populations from Java

The nyamplung biofuel content (CCO) of Javanese populations is as presented in Table 5. Variation between populations is evident in the six physical and chemical properties presented in Table 5, although it is not significant. The characteristic of nyamplung oil are similar among Java populations which is dark green, viscous and with strong aroma (Leksono and Putri, 2012). The physical performance of CCO might be influenced by shell residue and other chemicals such as alkaloid, phosphatide, carotenoid, chlorophyl and other dark constituents (Sudrajad and Hendra, 2012). Therefore degumming CCO to produce RCCO is essential, before processing into biokerosene and biodiesel (Table 5).

The results of pressing procedure and biofuel analyses (Table 5) demonstrates that the average biofuel contents from dry weight seed of the 6 Java population is 42.40% (CCO) and 41.04% (RCCO) and it varies among populations with 10% on the range of 37.02% - 48.57% (CCO) and 36.49 – 47.60% (RCCO). CCO contents processed by vertical hot press are higher in comparison to jatropha (25 - 40%),

Table 5. Calophyllum crude oil (CCO) and refined calophyllum crude oil (RCCO) contents of Nyamplung from 6 Java populations

No	Nyamplung Populations	Dry seeds (Kg)	Residual waste (Kg)	CCO (Kg)	CCO (%)	RCCO (Kg)	RCCO (%)
1.	Banyuwangi (East Java)	2.09	1.20	0.89	42.58	0.87	41.63
2.	Gunung Kidul (Jogjakarta)	2.10	1.08	1.02	48.57	1.00	47.60
3.	Purworejo (Central Java)	1.90	1.04	0.87	45.79	0.84	43.65
4.	Cilacap (Central Java)	2.10	1.25	0.85	40.48	0.78	37.24
5.	Ciamis (West Java)	2.00	1.20	0.80	40.00	0.79	39.60
6.	Pandeglang (Banten)	1.81	1.16	0.67	37.02	0.66	36.49
Average					42.40		41.04

sterculia (25 - 40%) and schleichera (27%) (Heyne, 1987; Sudrajad et al., 2010a; Sudrajad et al., 2010b; Hasnam, 2011; Raja et al., 2011). These findings show that nyamplung seeds are very promising as an alternative raw material for biofuel. The highest CCO and RCCO contents (Table 5) were obtained from the population of Gunung Kidul with the values of 48.57% and 47.60%, respectively, while the lowest values were obtained from Pandeglang (Banten) populations with 37.02% and 36.49%, respectively.

In general, biofuel contents of the 6 Java populations (CCO and RCCO) illustrate the variations among Java populations. This means that differences of genetic factors associated with population (intra-spesific variation) will affect the final production (Zobel and Talbert 1984). Variation of fruit and seed sizes of the same 6 populations from Java, are also evident (Table 5). This implies that differences of genetic factors from each nyamplung population will affect the physical characters of fruits and seeds that will be produced. These results indicate the lack of relationship between biggest fruit weight classification and their seed weight classification as well as there was no relationship between smallest fruit weight classification and their seeds (Leksono and Putri, 2012). There have been no reports on relationship between seed size and biofuel content. Seed size may not be the only factor influencing the contents, and variation of gum content among nyamplung populations may also affect biofuel contents.

B. Variations in Biofuel Potential of Seven Nyamplung Populations from Seven Islands in Indonesia

Seed pressing process to examine the potential of CCO from 7 islands in Indonesia was carried out by using 2 types of equipment: VHP for 3 populations and SPE for 7 populations. The biofuel potential (CCO, RCCO and biodiesel) of 7 populations from 7 islands in Indonesia are shown in Table 6.

Results show that use of SPE produce 5 - 13% higher CCO contents (in the range of 50 - 53%) than by use of VHP (40 - 45%). Table 6 shows that by use of SPE has also produced much higher nyamplung biofuel contents when compared to extraction from jatropha (25 - 50%), sterculia (25 - 40%) and schleichera (27%) (Heyne 1987, Sudradjad and Setiawan 2005; Sudrajad et al., 2010a, Sudrajad et al., 2010b, Hasnam 2011, Raja et al., 2011).

Table 6. Contents of CCO, RCCO, and nyamplung biodiesel from dry seed weight of nyamplung collected from 7 islands in Indonesia

No	Nyamplung Populations	Dry seed (Kg)	CCO (%)	RCCO (%)	Biodiesel (%)	Equipments used
1.	Gunung Kidul (Jogjakarta)	4.8	43.75	38.06	-	VHP
2.	Sumenep (Madura)	4.8	40.63	34.13	-	VHP
3.	Selayar (South Sulawesi)	4.8	45.63	40.15	-	VHP
4.	Gunung Kidul (Jogjakarta)	7.3	50.00	46.85	28.95	SPE
5.	Sumenep (Madura)	6.0	53.17	44.67	21.00	SPE
6.	Selayar (South Sulawesi)	6.0	50.17	40.67	30.00	SPE
7.	Pariaman (West Sumatera)	6.0	50.17	36.00	17.00	SPE
8.	Ketapang (West Kalimantan)*	6.0	27.50	24.50	18.70	SPE
9.	Dompu (NTB)	6.0	58.33	53.00	33.83	SPE
10.	Yapen (Papua)*	6.0	37.67	22.83	16.00	SPE

Note: *) = technical problems occurrred during the pressing process by using SPE,
VHP = Vertical Hot Press, SPE = Screw Press Expeller

This has encouraged the use of nyamplung as prospective alternative of raw material for biofuel production. Improvement of the processing for biofuel production is in progress. It is expected that the range of biofuel content produced in this study can be enhanced using more effective and efficient process of oil analyses.

Table 3 and Table 6 show different results in case of nyamplung from Gunung Kidul population. This may be affected by the different time of sample collections, where Table 3 shows fruit collection in 2010 and Table 6 shows collection in 2011. This information also describes the differences in biofuel contents even from the same population when seeds are collected at different time because the seeds are collected from open pollinated crossings. This also reveals that biofuel contents may vary depending on population origin, time of collection, age of tree and processing equipment (Sudradjad and Setiawan 2005, Sudrajad et al., 2010a, Sudrajad et al., 2010b, Hasnam 2011).

The highest contents of CCO, RCCO and biodiesel of the 7 populations from the 7 islands in Indonesia (Table 6) are obtained from the Dompu (NTB) populations with the values of 58.3%, 53.0% and 33.8% respectively, compared with biofuel contents from other populations with the values of 50 - 53%, 36 - 44% and 17 - 30%, respectively. Examination will be carried out later after obtaining seeds from the same populations. High variations of biofuel content between the 7 islands sampled Suggest that improvement program through selection among nyamplung provenances will be very effective and thus should be conducted.

Biodiesel contents of the 7 islands were then analyzed further for physical-chemical biodiesel properties based on SNI 04-7182-

Table 7. Physical-chemical properties of nyamplung biodiesel in comparison with SNI 04-7182 2006 standard

No.	Properties	Unit	Testing Methode	Spec. Biodiesel	Nyamplung Biodiesel
1.	Density at 40°C	kg/m^3	ASTM D.1298	850 - 890	895 – 903
2.	Kinematic viscosity at 40°C	cSt	ASTM D.445	2.3 – 6.0	5.7 – 6.5
3.	Flash point PMCC	°C	ASTM D.93	Min. 100	126 – 173
4.	Cetane index	-	ASTM D.613	Min. 51	59 – 72
5.	Cloud point	°C	ASTM D.2500	Max. 18	11 – 16
6.	Sediment and water content	% Vol.	ASTM D.1796	Max. 0.05	0
7.	Copperstrip corrosion at 3/50°C	No. ASTM	ASTM D.130	Max.no 3	1a – 1b
8.	Micro Carbon Residual (MCR)	% wt	ASTM D.4530	Max.0.05	0.6 – 0.9
9.	Sulphate Ash	% wt	ASTM D.874	Max.0.02	0.002 – 0.01
10.	Destilation at 90% Vol	°C	ASTM D.1160	Max. 360	365 – 369
11.	Sulphur content	mg/kg	ASTM D.4294	Max. 100	9 – 19
12.	Phosphor content	mg/kg	AOCS Ca 12-55	Max. 10	0.19 – 0.33
13.	Acid value	Mg KOH/g	ASTM D.974	Max. 0.8	0.05 – 0.08
14.	Free Glycerol	% wt	AOCS Ca 14-56	Max. 0.02	0.01 – 0.04
15.	Total Glycerol	% wt	AOCS Ca 14-56	Max.0.24	0.14 – 0.24
16.	Esther alkali	% wt	Calculation	Min. 96.5	98 – 99
17.	Iodine value	% wt	AOCS Cd 1-25	Max. 115	59 – 96
18.	Halphen test	-	AOCS Cb 1-25	Negative	Negative

2006 standard (Badan Standardisasi Nasional, 2006) as presented in Table 7.

Several physical-chemical properties of nyamplung biodiesel (Tabel 7) fulfill the requirements of SNI 04-7182-2006 standard, These are: flash point, cetane index, cloud point, sediment and water content, copper strip corrosionat, sulphat ash, sulphur, phosphor, acid value, total glycerol, esther alkali, iodine value and halphen test. Several parameters do not meet the standard. These are: specific gravity, kinematic viscousity, micro carbon residual, destilation and free glycerol.

In general, the biodiesel quality does not comply with the Indonesian Standard (SNI) for biodiesel, indicates the importance of improvement in the processing of CCO into biodiesel. From those biodiesel properties, cetane value determines the temperature of the burning point and easeness for the machine to start; acid value verifies the corrosive level of biodiesel to the machine ignition point determines the safety for transporting biodiesel due to its sensitivity to inflammation; esther alkali indicates the percentage of fatty acid converted into methyl esther; iodine value denotes the number of double bond in free fatty acid; viscosity implies biodiesel thickness that determines smoothness of the flowing in the machinery; fogging point relates to the easeness for biodiesel to frost. Other parameters are related to emission and pollution (Sudrajad and Hendra, 2012).

C. Genetic Diversity of Nyamplung

Understanding the genetic diversity of nyamplung populations is critical for genetic improvement. DNA analyses using RAPD was used to assesses genetic diversity in the sample populations. The results of this analysis suggest that nyamplung population in Java could be divided into two clusters at 99% significance level, and the 7 populations from the 7 islands in Indonesia could also be devided into two clusters at the 89% significance level (Figure 1 and Figure 2 - Nurtjahjaningsih, 2012).

IV. CONCLUSION

Oil content of nyamplung biofuel (CCO and RCCO) from 6 Java populations, processed using vertical hot press, range 37.02% - 48.57% and 36.49 - 47.60% respectively. The highest contents are produced by Gunung Kidul (Jogjakarta) population with 48.57% and 47.60%, and the lowest by Pandeglang (Banten) population with 37.02% and 36.49% respectively.

Oil content of nyamplung biofuel from the 7 populations of the 7 islands in Indonesia, processed by using vertical hot press, range 40.63 - 45.63% (CCO) and 38.06 - 40.15% (RCCO), and using screw press expeller, from 50.17 - 58.33% (CCO), 36 - 53% (RCCO) and 17 - 33.83% (biodiesel). The highest content is

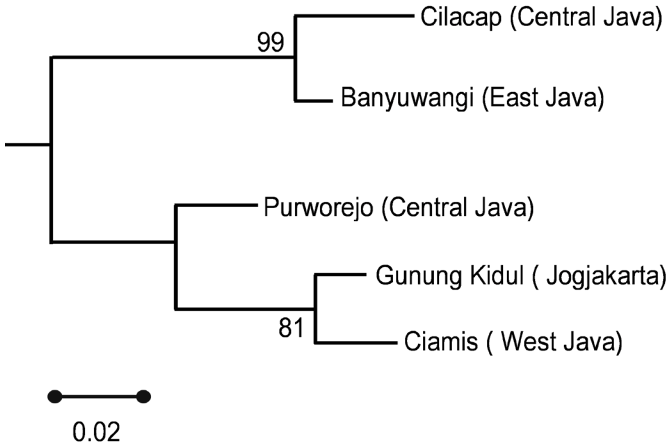

Figure 1. A dendrogram of nyamplung populations in Java

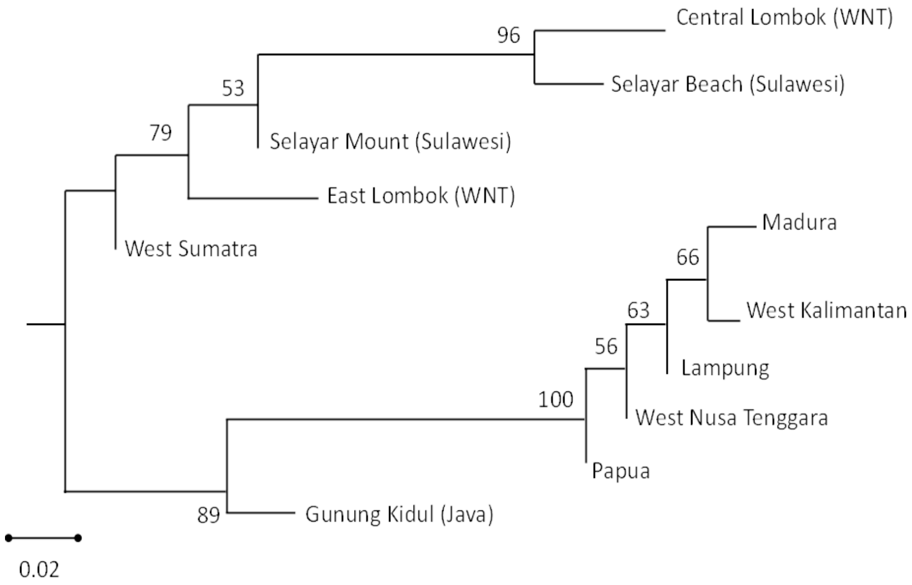

Figure 2. A dendrogram of nyamplung populations in Indonesia

produced by Dompu (NTB) population with 58.33%, 53% and 33.83% for CCO, RCCO and biodiesel, respectively.

Among 18 oil properties tested, 13 oil properties have met the Indonesian SNI 04-7182-2006 standard. CCO process of nyamplung biodiesel need to be enhanced in order to meet the standard.

A high variations of nyamplung biofuel content and high genetic diversity of 12 nyamplung populations in Indonesiaprovide promising potential for enhanching biofuel productivity through genetic improvement of nyamplung. Establishment of nyamplung populations with high biofuel potential outside its natural distribution require trials to evaluate their adaptive capability and the level of reproducing flower and fruit production.

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DIVERSITY OF PLANT COMMUNITIES IN SECONDARY SUCCESSION OF IMPERATA GRASSLANDS IN SAMBOJA LESTARI, EAST KALIMANTAN, INDONESIA

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ABSTRACT

Regeneration of Imperata grassland areas is becoming increasingly important, both to create new secondary forest and to recover the original biodiversity. The diversity of plant communities in secondary succession of Imperata grasslands was studied using 45 subplots of 9 linear transects (10 m x 100 m). Data was collected and all stems over 10 cm dbh were identified, the Importance Values Index (IVI) for all trees were calculated, saplings and seedlings were counted and analysed, and soil samples were taken and analysed. Results showed that after more than 10 years of regeneration, 65 families were encountered consisting of 164 species, which were dominated by *Vernonia arborea* Buch.-Ham, *Vitex pinnata* L., *Macaranga gigantea* (Reichb.f. & Zoll.) Muell.Arg., *Symplocos crassipes* C.B. Clarke, *Artocarpus odoratissimus* Miq., and *Bridelia glauca* Blume. The effects of regeneration, from Imperata grassland to secondary forest, on soil were the strongest in the A-horizon where an increase in carbon, N content, and pH were observed. Our result shows that Imperata grasslands appear to be permanent because of frequent fires and human interferences and so far few efforts have been made to promote sustainable rehabilitation. If protected from fire and other disturbances, such as shifting cultivation, Imperata grassland will grow and develop into secondary forest.

Keywords: Imperata grasslands, Importance Values Index, regeneration, secondary succession

ABSTRAK

Regenerasi alami pada lahan alang-alang menjadi semakin penting, baik untuk menciptakan hutan sekunder baru dan memulihkan keanekaragaman hayatinya. Kami mempelajari keanekaragaman komunitas tumbuhan dalam suksesi sekunder di lahan alang-alang menggunakan 45 subplot dari 9 transek linier (10 mx 100 m). Data yang dikumpulkan dan diidentifikasi dari semua jenis yang ditemukan dengan ukuran diameter setinggi dada lebih dari 10 cm, kemudian dihitung dan dianalisis Indek Nilai Penting (INP) baik untuk tingkat pohon, sapling dan anakan, dan sampel tanah yang diambil kemudian dianalisis. Hasil penelitian menunjukkan bahwa selama proses regenerasi setelah lebih dari 10 tahun, 65 famili ditemukan dimana terdiri dari 164 jenis, yang didominasi oleh *Vernonia arborea* Buch.-Ham, *Vitex pinnata* L., *Macaranga gigantea* (Reichb.f. & Zoll.) Muell.Arg ., *Symplocos crassipes* CB Clarke, *Artocarpus odoratissimus* Miq., dan *Bridelia glauca* Blume. Pengaruh regenerasi dari lahan alang-alang menjadi hutan sekunder terhadap kondisi tanah terkuat di horizon-A, dimana terjadi peningakatan Karbon, Nitrogen dan pH. Hasil penelitian ini menunjukkan bahwa lahan alang-alang tampak permanen karena mengalami kebakaran yang berulang dan campur tangan manusia dan sejauh ini masih sedikit upaya yang telah dilakukan untuk melakukan merehabilitasi yang berkelanjutan. Jika dilindungi dari kebakaran dan gangguan lain seperti peladang berpindah, lahan alang-alang akan tumbuh dan berkembang menjadi hutan sekunder.

Kata kunci: Lahan alang-alang, Indek Nilai Penting, regenerasi, suksesi

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I. INTRODUCTION

East Kalimantan is one of the important tropical forest habitats in the world. Nowadays, large areas of primary forest in East Kalimantan have been changed into secondary forests, like oil palm plantations, timber estate plantations, slash-and-burn agricultures, coal mining as well as Imperata grasslands. In East Kalimantan alone, the rate of deforestation from 2003 to 2006 was around 248,500 ha per year (Ministry of Forestry, 2008).

MacKinnon et al. (1996) mentioned that Imperata grasslands were caused by logging, forest clearing for shifting cultivation, agriculture and grazing, and also by fire. The latter is a result of frequent human interference. When Imperata grasslands are abandoned and not burned regularly, they will undergo a series of vegetation changes, a process called secondary succession. Leps (1987) argued that this early stage of succession influences the later stages of vegetation development, which in turn determine the character of the secondary forest and the recovery of the original biodiversity.

Although the direction of the (early) secondary succession in Imperata grasslands is important, this aspect was hardly investigated in Indonesia. Most studies in Indonesia focused on tropical secondary forests (Brealey et al., 2004; Bischoff et al., 2005). Okimori and Matius (2000) described the secondary forest succeeding traditional slash-and-burn agriculture; in addition Kiyono and Hastaniah (2000) studied the role of slash-and-burn agriculture in transforming dipterocarp forest into Imperata grassland.

Some studies described the effect of fire on tree species composition of lowland dipterocarp forest (Ohtsuka, 1999; Matius et al., 2000; Hashimotio et al., 2000; Slik et al., 2002; Slik and Eichhorn, 2003; Hiratsuka et al., 2006). Recent study by Yassir et al. (2010) described the pathways of the secondary succession in Imperata grasslands in East Kalimantan on the same location where this study was made. However, Yassir et al., (2010) focused only on understorey species and vegetation that was less than 3.5 m, but vegetation that was higher than 3.5 m was not sampled.

The paper describes diversity of plant communities upon secondary succession from Imperata grasslands to young secondary forest with more than 10 years of regeneration time. The objectives of this study were (a) to examine how diversity of plant community develops after fire; and (b) to determine whether Imperata grasslands were a final and stable stage of land degradation.

II. MATERIAL AND METHOD

A. Study Area

The study was conducted at Samboja Lestari area (Figure 1), a 1,850 ha reforestation project managed by the Borneo Orangutan Survival Foundation (BOSF). The Köppen system classified the climate of the research area as Af (tropical rainforest). Average yearly precipitation is about 2,250 mm with a wet period from December to May. The driest month had an average precipitation of 132 mm, and the wettest month of 231 mm. The daily maximum temperature varied from 23 to 31°C and the relative humidity was high, around 78 to 94%. The soils were formed on marine sediments of Tertiary age. Top soils were generally slightly coarser than the deeper layers. In the Food and Agriculture Organization (FAO) classification system (FAO, 2001) the soils of Samboja Lestari was classified as acrisols.

B. Data Collection

All field data were collected in the area of Samboja Lestari (secondary succession). In total there were 45 subplots out of 9 linear transects (10 m x 100 m). We collected and identified data of all living trees with a Diameter at Breast Height (DBH) more than 10 cm (trees) (10 m x 20 m); DBH 5 and <10 cm (saplings) (5 m x 5 m); DBH< 5 cm and a height < 1.3 m (seedlings including shrubs and herbs) (2 m x 2 m). All plant samples were identified to

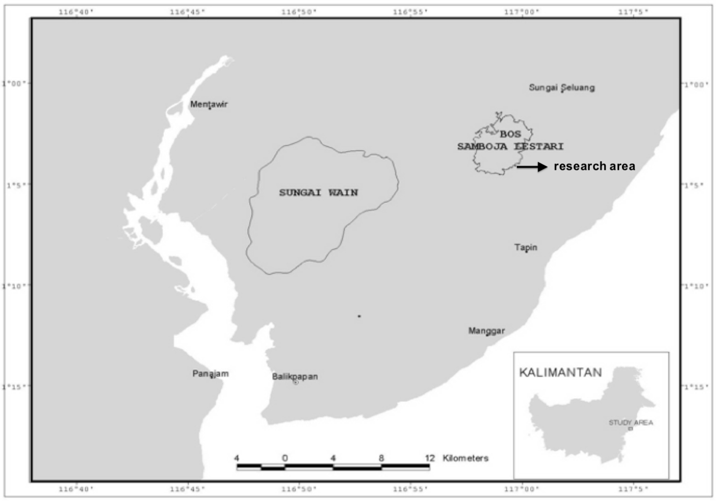

Figure 1. Location of BOS Samboja Lestari, East Kalimantan

the lowest possible taxonomic level. The soil sample of our previous study was collected in similar location and was used for this research (van der Kamp et al., 2009; Yassir et al., 2010). Soil samples were taken from the A-, AB- and B-horizon. As for chemical analyses, samples were taken from the full depth of each horizon. Samples were then taken to the laboratory in labelled plastic bags.

C. Data Analysis

All field data were analysed in spreadsheets of Microsoft Excel. The Importance Values Index (IVI) of each tree species were calculated by summing up the relative density, relative dominance and relative frequency. Whereas, the importance values of each species for saplings and seedlings were calculated by summing up the relative density and relative frequency (Mueller-Dombois and Ellenberg, 1974). Methods of soil analysis were listed by van der Kamp et al., (2009) and Yassir et al., (2010). Bulk density of all horizons was measured at Samboja Lestari, using triplicate measurements with 100 cm^3 cylinders. Chemical properties were measured at the Soil Science Laboratory of Bogor Agricultural University (Bogor, Indonesia). Chemical measurements included total C determined by Walkley-Black (A-, AB- and B-horizon), available K determined by Bray I extraction and flame photometer (A- and B-horizon), total N determined by Kjeldahl/titrimetric (macro; A-horizons only), available P determined by Bray I extraction (A- and B-horizon), pH determined in 1:1 (soil: water) suspension with a pH meter (A-horizon only).

III. RESULT AND DISCUSSION

A. Community Structure

Based on our 45 subplots with a total area of 0.9 ha in secondary forest, 65 families were encountered consisting of 164 species (Appendix 1). Based on the Important Value Index, the tree species were dominated by *Vernonia arborea*, *Vitex pinnata*, *Macaranga gigantea*, *Symplocos crassipes*, *Artocarpus odoratissimus*, and *Bridelia glauca* (Table 1). The important value index of species of saplings was dominated by *Fordia splendidissima*, *Symplocos crassipes*, *Macaranga trichocarpa*, *Malastoma malabathricum*, *Vitex pinnata* and *Macaranga beccariana*. While, the Important Value Index of species of seedlings including shrubs and herbs were dominated by *Nephrolepis bisserrata*, *Bridelia glauca*, *Fordia splendidissima*, *Scleria terrestris*, *Lygodium circinatum* and *Psychotria* sp.

Furthermore, Kiyono and Hastaniah (1997) reported in their study in East Kalimantan that one hectare of Imperata grassland contained

Table 1. List of dominance of 10 species based on the Important Value Index (IVI)

Stages	No.	Species	Family	IVI(%)
Trees	1.	*Vernonia arborea*	Asteraceae	62.5
	2.	*Vitex pinnata*	Verbenaceae	40.9
	3.	*Macaranga gigantea*	Euphorbiaceae	27.9
	4.	*Symplocos crassipes*	Symplocaceae	15.3
	5.	*Artocarpus odoratissimus*	Moraceae	11.8
	6.	*Bridelia glauca*	Euphorbiaceae	10.2
	7.	*Artocarpus tamaran*	Moraceae	7.9
	8.	*Melicope glabra*	Rutaceae	6.8
	9.	*Geunsia pentandra*	Verbenaceae	5.6
	10.	*Schima wallichii*	Theaceae	4.9
Saplings	1.	*Fordia splendidissima*	Leguminosae-Papilionoideae	29.0
	2.	*Symplocos crassipes*	Symplocaceae	12.0
	3.	*Macaranga trichocarpa*	Euphorbiaceae	11.3
	4.	*Melastoma malabathricum*	Melastomataceae	10.1
	5.	*Vitex pinnata*	Verbenaceae	10.1
	6.	*Macaranga beccariana*	Euphorbiaceae	8.8
	7.	*Bridelia glauca*	Euphorbiaceae	8.2
	8.	*Vernonia arborea*	Asteraceae	7.2
	9.	*Dillenia suffruticosa*	Dilleniaceae	7.0
	10.	*Macaranga gigantea*	Euphorbiaceae	6.9
Seedlings (including shrubs and herbs)	1.	*Nephrolepis biserrata*	Neprolepidaceae	18.1
	2.	*Bridelia glauca*	Euphorbiaceae	13.0
	3.	*Fordia splendidissima*	Leguminosae-Papilionoideae	11.3
	4.	*Scleria terrestris*	Cyperaceae	11.0
	5.	*Lygodium circinatum*	Schizaeaceae	7.6
	6.	*Psychotria* sp.	Rubiaceae	7.3
	7.	*Melastoma malabathricum*	Melastomataceae	6.1
	8.	*Curculigo racemosa*	Amaryllidaceae	5.6
	9.	*Macaranga beccariana*	Euphorbiaceae	5.5
	10.	*Clidemia hirta*	Melastomataceae	5.3

Key: FW= fruit weight, SS= seed shell , WS= wet seed, DS= dry seed

up to 107 plant species, including trees such as *Vernonia arborea*, *Cratoxylum formusum* and *Vitex pinnata*. Hashimotio et al. (2000) reported that after 10-12 years of fallow, the dominant species in regenerated lowland forest in Borneo were *Piper aduncum*, *Ficus* sp, *Geunsia pentandra*, *Vernonia arborea*, *Melastoma malabathricum*, *Macaranga* sp., and *Bridelia glauca*. Hiratsuka et al. (2006) reported that after the 1998 forest fires in East Kalimantan, the dominant pioneer species were *Homalantus populneus*, *Macaranga gigantea*, *Macaranga hypoleuca*, *Mallotus paniculatus*, *Melastoma malabathricum*, *Piper aduncum* and *Trema orientalis*. All these species are described by Kiyono and Hastaniah (1997), Hashimotio et al. (2000) and Hiratsuka et al. (2006) were also identified during our field research.

Compared to our previous study at the same location (Yassir et al., 2010), after three years of regeneration, *Imperata cylindrica* had the highest average coverage; it became less dominant from the fourth year onward. The average cover of *Pteridium aquilinum* is initially low but increases after 4 and 9 years of regeneration and also the average percentage of shrubs and young trees have increased significantly over time. In the secondary forest other tree species have taken over, and both *Imperata* and *Pteridium* have disappeared. Yassir et al., (2010) also reported that after three years of regeneration, *Melastoma malabathricum*, *Eupatorium inulaefolium*, and *Ficus* sp. were dominant species. There was a slight change in the 4-year old growth, where *Melastoma malabathricum*, *Eupatorium inulaefolium*, and *Ficus* sp. became the dominant species. After nine years of regeneration, *Melastoma malabathricum*, *Eupatorium inulaefolium* and *Vitex pinnata* were dominant species following the time of regeneration in Imperata grasslands.

In order to the family dominancy, Euphorbiaceae, Moraceae, Rubiaceae and Lauraceae were the dominant families (Figure 2). Based on our result, the dominant family of Euphorbiaceae is not surprising because Euphorbiaceae family is one of the major families in tropical rain forest in Borneo besides the Dipterocarpaceae family (MacKinnon et al., 1996).

Additionally, distribution pattern of diameter classes upon secondary succession in Imperata grassland showed that the number of species with diameter 10 cm-15 cm were dominant (51.2%), followed by diameter 15 cm-20 cm (28.1%) and diameter 20 cm-25 cm (13.0%)

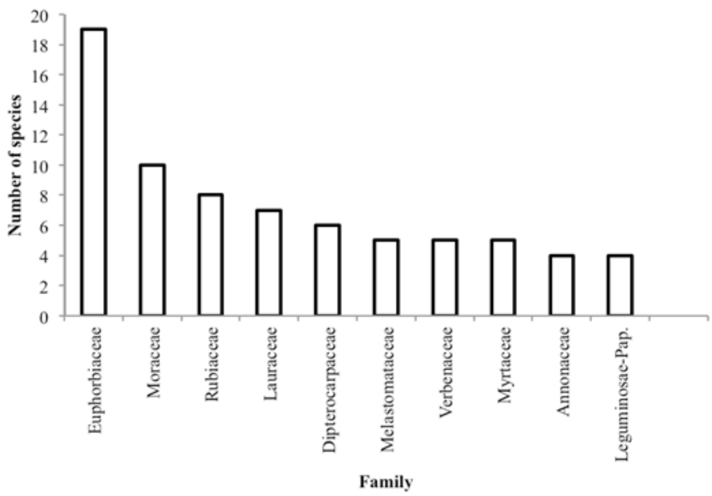

Figure 2. Total observed number of species based on the dominance of 10 families in Samboja Lestari (including seedlings stage)

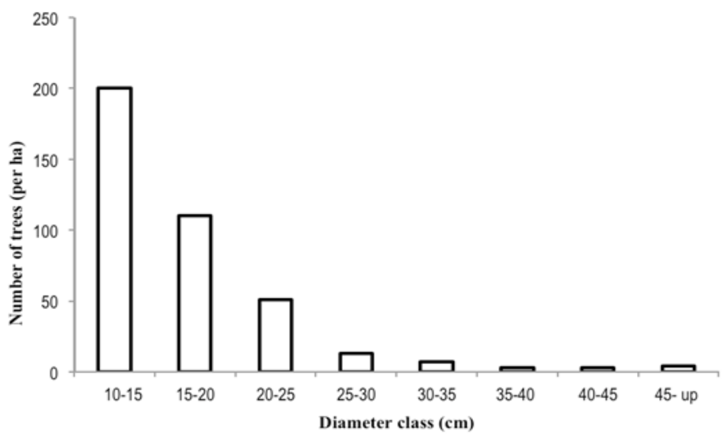

Figure 3. Distribution pattern of diameter classes in secondary succession of Samboja Lestari forest

Table 2. Soil properties and dominant species in sampled plots at Samboja Lestari

Regeneration Stage	Means							Dominant species
	Bd[a)] (g cm^{-3})	pH	C (g kg^{-1})	N (g kg^{-1})	C/N	P (mg kg^{-1})	K (cmol^{+} kg^{-1})	
3 years (n=47)								
A-horizon	1.18	5.29	14.52	1.43	10.53	4.04	0.16	*I. cylindrica*
AB-horizon	1.32		8.99					*E. inulaefolium*
B-horizon	1.38		3.75			3.16	0.11	
9 years (n=126)								
A-horizon	1.10	5.09	15.96	1.54	10.36	4.47	0.16	*M. malabathricum*
AB-horizon	1.34		9.10					*E. inulaefolium*
B-horizon	1.39		3.99			3.72	0.11	*V. arborea*
Secondary forest (±15 years; n=43)								
A-horizon	1.10	5.11	16.71	1.58	10.58	4.08	0.18	*V. arborea*
AB-horizon	1.32		8.93					*V. pinnata*
B-horizon	1.41		4.04			3.60	0.10	*S. crassipes* *Macaranga* sp.

*) Bd[a]) = bulk density

(Figure 3). The distribution pattern of diameter classes upon secondary succession in Imperata grassland was represented as reversed J shape. The shape of the reversed J is typical of self-regenerating communities or it describes that the process of regeneration is going well (Felfili, 1997).

B. Soil Properties in Different Phases of Regeneration

Based on our previous study (Yassir et al., 2010), soil properties in different phases of regeneration indicated that carbon, nitrogen content and pH in the A-horizon showed a small increase with the regeneration stage from Imperata grassland to young secondary forest (Table 2). When the vegetation was reduced to ashes through burning, as happened in the grassland plots, the pH increased due to the formation of carbonates (Binkley et al., 1989; Cruz and del Castillo, 2005; Farley et al., 2008). Bulk density generally increases with depth. Bulk density of the A-horizon was fairly high in most recently burned fields. It has decreased during the first phases of succession to secondary forest, possibly due to the appearance of the undergrowth. The carbon content of the A-horizon was the lowest in most recently burned plots. It was increased in the first phases of regeneration from Imperata grassland to secondary forest.

Table 2 also shows that there was no significant increase in P and K over time of secondary succession, which may indicate either a limited stock in the soil or leaching from the system. Leaching of P is unlikely, and therefore a limited supply is probably the best explanation. Yassir et al., (2010) also reported that soil properties had a strong influence on vegetation composition particularly pH, bulk density, sand and clay. Kooch et al., (2007) explained that soil texture and bulk density control the distribution of plant species by affecting moisture availability, ventilation and plant roots distribution. Schoenholtz et al., (2000) mentioned that the relation between bulk density, water and oxygen supply, and soil texture is the most fundamental soil physical property controlling water, nutrient, and oxygen exchange, retention and uptake. More detailed information related to Table 2 is described by van der Kamp et al. (2009) and Yassir et al. (2010).

IV. CONCLUSION

After more than 10 years of regeneration, 65 families were encountered consisting of 164 species, which were dominated by *Vernonia arborea*, *Vitex pinnata*, *Macaranga gigantea*, *Symplocos crassipes*, *Artocarpus odoratissimus*, and *Bridelia glauca*. Our result shows that Imperata grasslands seem to be permanent because of frequent fires and human interferences and so far few efforts have been made to encourage sustainable rehabilitation. If protected from fire and other disturbances such as shifting cultivation, Imperata grassland will develop into secondary forest. Therefore, the assumption that Imperata grasslands are a final stage of land degradation and are very difficult to recover for more valuable land uses is wrong and thus cannot be accepted. The introduction of native shrubs and trees will assist to speed up the process of succession from Imperata grasslands into secondary forest.

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Appendix I. List of all species recorded in young secondary forest in Samboja Lestari

No.	Family	Species
1	Acanthaceae	*Hygropila erecta* (Burm.f.) Hochr.
2	Amaryllidaceae	*Curculigo latifolia* (Dryand. ex W.T. Aiton)
3	Amaryllidaceae	*Curculigo racemosa* Ridl.
4	Anacardiaceae	*Dracontomelon dao* (Blanco) Merr. & Rolfe
5	Anacardiaceae	*Mangifera caesia* Jack
6	Anacardiaceae	*Mangipera indica* L,.
7	Anacardiaceae	*Mangipera pajang* Kosterm.
8	Annonaceae	*Artabotrys suaveolens* (Blume) Blume
9	Annonaceae	*Mitrephora korthalsiana* Miq.
10	Annonaceae	*Popowia pisocarpa* (Blume) Endl.
11	Annonaceae	*Uvaria elmeri* Merr.
12	Apocynaceae	*Tabernaemontana macrocarpa* Korth. ex Blume
13	Apocynaceae	*Willughbeia angustifolia* (Miq.) Markgr.
14	Aquifoliaceae	*Ilex cymosa* Blume
15	Arecaceae	*Calamus* sp.
16	Aristolochiaceae	*Aristolochia jackii* Steud.
17	Asteraceae	*Eupatorium inulaefolium* Kunth
18	Asteraceae	*Vernonia arborea* Buch.-Ham.
19	Bignoniaceae	*Dolicandrone* sp.
20	Blechnaceae	*Stenochlaena palustris* (Burm.) Bedd.
21	Celastraceae	*Lophopetalum javanicum* (Zoll.) Turez,.
22	Celastraceae	*Salacia macrophylla* Blume
23	Compositae	*Mikania scandens* Willd.
24	Connaraceae	*Roureopsis acutipetala* (Miq.) Leenh.
25	Cornaceae	*Alangium javanicum* Blume
26	Cucurbitaceae	*Trichosanthes sp.*
27	Cyperaceae	*Mapania longiflora* C.B. Clarke
28	Cyperaceae	*Scleria terrestris* (L,.) Fass.
29	Datiscaceae	*Octomeles sumatrana* Miq.
30	Dilleniaceae	*Dillenia suffruticosa* (Griff.) Martelli
31	Dilleniaceae	*Tetracera macrophylla* Wall. ex Hook.f. & Thoms.
32	Dipterocarpaceae	*Cotylelobium melanoxylum* (Hook.f.) Pierre
33	Dipterocarpaceae	*Hopea dryobalanoides* Miq.
34	Dipterocarpaceae	*Parashorea tomentela* (Symington) Meijer
35	Dipterocarpaceae	*Shorea johorensis* Foxw.
36	Dipterocarpaceae	*Shorea leprosula* Miq.
37	Dipterocarpaceae	*Shorea smithiana* Sym.
38	Ebenaceae	*Diospyros borneensis* Hiern
39	Ebenaceae	*Diospyros confertiflora* (Hiern) Bakh.
40	Ebenaceae	*Diospyros sumatrana* Miq.
41	Elaeocarpaceae	*Elaeocarpus glaber* Blume
42	Elaeocarpaceae	*Elaeocarpus stipularis* Blume
43	Euphorbiaceae	*Aporosa nitida* Merr.
44	Euphorbiaceae	*Baccaurea motleyana* (Muell.Arg.) Muell.Arg.
45	Euphorbiaceae	*Baccaurea sumatrana* (Miq.) Muell.Arg.
46	Euphorbiaceae	*Breynea racemosa* (Blume) Muell.Arg.
47	Euphorbiaceae	*Bridelia glauca* Blume
48	Euphorbiaceae	*Cleistanthus myrianthus* (Hassk). Kurz
49	Euphorbiaceae	*Galearia fulva* (Tul.) Miq.
50	Euphorbiaceae	*Glochidion arborescens* Blume
51	Euphorbiaceae	*Glochidion* sp.
52	Euphorbiaceae	*Homallanthus populneus* (Geiseler) Pax
53	Euphorbiaceae	*Macaranga beccariana* Merr.
54	Euphorbiaceae	*Macaranga gigantean* (Reichb.f. & Zoll.) Muell.Arg.
55	Euphorbiaceae	*Macaranga motleyana* (Muell.Arg.) Muell.Arg.
56	Euphorbiaceae	*Macaranga pruinosa* (Miq.) Muell.Arg.
57	Euphorbiaceae	*Macaranga tanarius* (L,.) Muell. Arg.
58	Euphorbiaceae	*Macaranga trichocarpa* (Reichb.f. & Zoll.) Muell.Arg.
59	Euphorbiaceae	*Mallotus paniculatus* (Lam.) Muell.Arg.
60	Euphorbiaceae	*Omphalea bracteata* (Blanco) Merr.
61	Euphorbiaceae	*Trigonostemon laevigatus* Muell.Arg.
62	Fagaceae	*Castanopsis* sp.
63	Gleicheniaceae	*Dicranopteris linearis* (Burm.f.) C.B. Clarke.
64	Graminae	*Imperata cylindrica* (L,.) Beauv.

65	Graminae	*Saccharum sponthaneum* L,.
66	Guttiferae	*Calophyllum nodusum* Vasque
67	Guttiferae	*Calophyllum* sp.
68	Hypericaceae	*Cratoxylum formosum* (Jack) Dyer
69	Hypericaceae	*Cratoxylum sumatranum* (Jack) Blume
70	Hypolepidaceae	*Pteridium aquilinum* (L,.) Kuhn
71	Lauraceae	*Alseodaphne peduncularis* (Wall. ex Nees) Meissn.
72	Lauraceae	*Cryptocarya crassinervia* Miq.
73	Lauraceae	*Dehaasia peduncularis* Meisn.
74	Lauraceae	*Eusideroxylon zwageri* Teijsm. & Binn.
75	Lauraceae	*Litsea angulata* Blume
76	Lauraceae	*Litsea firma* (Blume) Hook.f.
77	Lauraceae	*Litsea* sp.
78	Lecythidaceae	*Barringtonia macrostachya* Jack
79	Leguminosae-Caes.	*Bauhinia excelsa* (Miq.) Prain
80	Leguminosae-Mim.	*Archidendron jiringa* (Jack) I.C. Nielsen
81	Leguminosae-Mim.	*Archidendron microcarpum* (Benth.) I.C. Nielsen
82	Leguminosae-Mim.	*Paraserianthes falcataria* (L,.) I.C. Nielsen
83	Leguminosae-Pap.	*Dalbergia abbrevialata* Craib
84	Leguminosae-Pap.	*Fordia splendidissima* (Blume ex Miq.) Buijsen
85	Leguminosae-Pap.	*Spatholobus ferrugineus* Benth.
86	Leguminosae-Pap.	*Spatholobus hirsutus* H. Wiriadinata & J.W.A. Ridder-Numan
87	Liliaceae	*Dracaena elliptica* Thunb.
88	Liliaceae	*Smilax odoratissima* Blume
89	Loganiaceae	*Fagraea racemosa* Jack ex Wall.
90	Lycopodiaceae	*Lycopodium cernuum* L,.
91	Magnoliaceae	*Magnolia tsiampacca* (L,.) Dandy
92	Malvaceae	*Sida* sp.
93	Malvaceae	*Urena lobata* L,.
94	Marantaceae	*Phrynium borneensis* Blume
95	Marantaceae	*Stachyphrynium borneensis* (K. Koch) K. Schum.
96	Melastomataceae	*Clidemia hirta* D. Don
97	Melastomataceae	*Melastoma malabathricum* L,.
98	Melastomataceae	*Pternandra azurea* (Blume) Burkill
99	Melastomataceae	*Pternandra* sp.
100	Melastomataceae	*Pternandra rostrata* (Cogn.) M.P. Nayar
101	Meliaceae	*Chisocheton ceramicus* (Miq.) C.DC.
102	Meliaceae	*Heynea trijuga* (Roxb.) ex Sims
103	Menispermaceae	*Pericamphyllus glaucus* (Lam.) Merr.
104	Moraceae	*Artocarpus anisophyllus* Miq.
105	Moraceae	*Artocarpus dadah* Miq.
106	Moraceae	*Artocarpus integer* (Thunb.) Merr.
107	Moraceae	*Artocarpus nitidus* Trec. subsp. borneense
108	Moraceae	*Artocarpus odoratissimus* Miq.
109	Moraceae	*Artocarpus tamaran* Becc.
110	Moraceae	*Ficus aurata* Miq.
111	Moraceae	*Ficus obscura* Blume
112	Moraceae	*Ficus* sp.
113	Moraceae	*Ficus variegata* Blume
114	Myristicaceae	*Knema latericia* Elmer
115	Myrsinaceae	*Embelia javanica* DC.
116	Myrsinaceae	*Maesa ramentacea* Wall.
117	Myrtaceae	*Eugenia caudatilimba* Merr.
118	Myrtaceae	*Rhodamnia cinerea* Jack
119	Myrtaceae	*Syzygium lineatum* (DC) Merr. & Perry
120	Myrtaceae	*Syzygium* sp.
121	Myrtaceae	*Syzygium tawahense* (Korth.) Merr. & Perry
122	Neprolepidaceae	*Nephrolepis biserrata* (Sw.) Schott.
123	Neprolepidaceae	*Nephrolepis* sp.
124	Pandanaceae	*Freycinetia* sp.
125	Passifloraceae	*Passiflora foetida* L,.
126	Piperaceae	*Piper aduncum* L,.
127	Polygalaceae	*Xanthophyllum affine* Korth. ex Miq.
128	Polygalaceae	*Xanthophyllum rufum* A.W. Benn.
129	Rhamnaceae	*Alpitonia excelsa* (Fenzl) Reiss ex Endl.
130	Rubiaceae	*Gardenia tubifera* Wall.
131	Rubiaceae	*Hedyotis congesta* Wall. ex G. Don
132	Rubiaceae	*Nauclea subdita* Merr.

133	Rubiaceae	*Pertusadina eurhyncha* Ridsdale
134	Rubiaceae	*Pleiocarpidia polyneura* (Miq.) Bremek.
135	Rubiaceae	*Psychotria* sp.
136	Rubiaceae	*Timonius flavescens* (Jack) Baker
137	Rubiaceae	*Urophyllum arborescens* (Reinw. ex Blume) Korth.
138	Rutaceae	*Melicope glabra* (Blume) T.G. Hartley
139	Sapindaceae	*Guioa* sp.
140	Sapindaceae	*Lepisanthes amoena* (Hassk.) Leenh.
141	Sapindaceae	*Nephelium cuspidatum* (Blume) var. *eriopetalum* (Miq.) Leenh.
142	Sapotaceae	*Madhuca sericea* (Miq.) H.J. Lam
143	Sapotaceae	*Palaquium quercifolium* (de Vriese) Burck
144	Schizaeaceae	*Lygodium circinatum* (Burm.f.) S.w.
145	Schizaeaceae	*Lygodium microphyllum* (Cav.) R.Br.
146	Solanaceae	*Solanum jamaicence* Mill.
147	Sterculiaceae	*Heritiera elata* Ridl.
148	Sterculiaceae	*Sterculia rubiginosa* Vent
149	Symplocaceae	*Symplocos crassipes* C.B. Clarke
150	Theaceae	*Schima wallichii* (DC.) Korth.
151	Tiliaceae	*Pentace laxiflora* Merr.
152	Tiliaceae	*Pentace triptera* Mast.
153	Ulmaceae	*Trema tomentosa* (Roxb). Hara
154	Ulmaceae	*Gironniera nervosa* Planch.
155	Verbenaceae	*Clerodendrum adenophysum* Hallier f.
156	Verbenaceae	*Clerodendrum disparifolium* Blume
157	Verbenaceae	Clerodendrum sp.
158	Verbenaceae	*Geunsia pentandra* Merr.
159	Verbenaceae	*Vitex pinnata* L,.
160	Vitaceae	*Tetrastigma* sp.
161	Vitaceae	*Tetrastigma pedunculare* (Wall.) Planch.
162	Zingiberaceae	*Alpinia galanga* Willd.
163	Zingiberaceae	*Costus speciosus* (Koenig) Smith
164	Zingiberaceae	*Etlingera* sp.

AUTHOR INDEX

SUBJECT INDEX

GUIDELINE FOR AUTHORS

AIM AND SCOPE

The journal publishes primary research findings and synthesized articles containing significant contribution to science and its theoretical application in areas related to the scope of Indonesian forestry research. Scope of the journal includes: silviculture, forest management, forest biometrics, forest economics, forest entomology and pathology, forest fire fuels management, forest ecology, forest genetics and tree improvement, geospatial technologies, forest harvesting and utilization, wood science, forest landscape and ecology, forest operations research, forest policy, forest physiology, forest ecotourism, social forestry, forest soils and hydrology, and wildlife management. Overseas works relevant to Indonesian conditions may be accepted for consideration.

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REFERENCES: At least 10 references; referring to APA style 6th edition; organized alphabetically by author name; 80% from last 5 years issues; and 80% from primary reference sources, except for specific science textbooks (mathematics, taxonomy, climate).

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