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ABSTRACTS

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Asep Hidayat and Sanro Tachibana

EFFECT OF PIPERONYL BUTOXIDE AND SILVER NITRATE ON DEGRADATION PATHWAYS OF N-OCTADECANE BY *Fusarium* sp. F092

(PENGARUH PIPERONIL DAN PERAK NITRAT DALAM JALUR PENGURAIAN n-OKTADEKANA OLEH *Fusarium* sp. F092*)*

Susunan senyawa yang paling besar terdapat di minyak mentah adalah senyawa alifatik. Remediasi senyawa alifatik pada areal terkontaminasi minyak mentah menjadi perhatian utama masalah lingkungan dan bisa menjadi tolok ukur dalam upaya pemulihan areal tercemar. Penelitian sebelumnya menemukan bahwa jamur *Fusarium* sp. F092 mampu mengurai chrysene dan senyawa alifatik yang menjadi penyusun ceceran minyak mentah. Akan tetapi khusus untuk penguraian senyawa alifatik, mekanisme jalur degradasi oleh F092 belum terungkap secara jelas. Penelitian ini bertujuan untuk mengidentifikasi mekanisme degradasi senyawa alifatik dengan menggunakan satu senyawa tunggal alifatik *n*-oktadekana berikut pengaruh pemberian Piperonyl Butoxide (PB) dan Perak Nitrat ($AgNO_3$) dalam penguraian n-oktadekana. Hasil penelitian menunjukkan bahwa *Fusarium* sp. F092 mampu mengurai n-oktadekana dari konsentrasi awal 125 mg L^{-1}menjadi 13 mg L^{-1}selama 60 hari masa inkubasi. Beberapa senyawa metabolit hasil penguraian dapat terdeteksi dan teridentifikasi sebagai kelompok senyawa asam karboksilat. Dengan penambahan PB dan $AgNO_3$ sebagai penghambat aktivitas enzim dioxygenase dan monooxygenase, dapat diketahui bahwa penguraian *n*-oktadekana oleh *Fusarium* sp. F092 diawali dengan merubah *n*-oktadekana menjadi alkyl hydroperoxides melalui jalur terminal oksidasi dengan melibatkan enzim dioxygenase.

Kata kunci: *n*-Oktadekana, alifatik, biodegradation, produk metabolit, enzim, *Fusarium* sp. F092

UDC/ODC 630*89

Djarwanto and Sihati Suprapti

UTILIZATION OF AREN (*Arenga pinnata* Merr.) SAWMILLING WASTE FOR EDIBLE MUSHROOM CULTIVATION MEDIA

(PEMANFAATAN LIMBAH PENGGERGAJIAN KAYU AREN (*Arenga pinnata* Merr.) UNTUK MEDIA BUDIDAYA JAMUR KAYU YANG DAPAT DIMAKAN)

Aren (*Arenga pinnata* Merr.) termasuk ke dalam kelompok pohon serbaguna: niranya dibuat gula dan minuman beralkohol, buahnya untuk cocktail, kayunya untuk kostruksi bangunan. Studi pemanfaatan serbuk gergajian kayu aren belum dilakukan secara intensif. Penelitian ini bertujuan untuk mengkaji pemanfaatan serbuk gergajian kayu aren untuk media budidaya jamur kayu yang dapat dimakan. Serbuk gergajian kayu aren dicampur dengan dedak, $CaCO_3$, gypsum, pupuk dan air suling dengan komposisi tertentu kemudian disterilkan dengan autoklaf selama 30 menit pada suhu 121°C dan tekanan 1.5 atmosfer. Setelah dingin, kantong-kantong media dibagi 4 kelompok, masing-masing diinokulasi dengan biakan murni empat jenis jamur, yaitu: *Pleurotus flabellatus*, *P. ostreatus*, *P. sajor-caju*, dan *Lentinula edodes* kemudian diinkubasikan selama kurang lebih lima minggu untuk memberi kesempatan tumbuhnya miselium membentuk tubuh buah jamur. Jamur dipanen setiap hari selama tubuh buahnya tumbuh sampai sekitar 4 bulan. Data hasil panen per kantong media diakumulasikan kemudian dihitung nilai efisiensi konversi biologinya (EB). Selain itu, limbah berupa hati batang aren dibuat contoh uji dengan ukuran lebar 10 cm, tebal 5 cm dan panjang 120 cm. Contoh uji dilubangi dengan bor pada jarak tertentu, kemudian ke dalam setiap lubang diinokulasi biakan murni 6 jenis jamur yaitu 4 jenis sama seperti pada media serbuk gergajian ditambah dua jenis yaitu *P. cystidiosus*, dan *Auricularia polytricha*. Contoh uji yang sudah diinokulasi jamur disandarkan sedemikian rupa di dalam gubug bambu. Panen jamur dilakukan setiap hari setelah tubuh buah masak petik. Seperti halnya pada serbuk gergajian, hasil panen jamur ditimbang. Hasilnya menunjukkan bahwa penggunaan media dari serbuk gergajian kayu aren yang mengandung suplemen lebih baik dibandingkan dengan media hati batang aren. Nilai EB pada media dari serbuk gergajian kayu aren yaitu 21.97-89.45 % (*Pleurotus flabellatus*), 15.36-105.36 % (*P. ostreatus*), 63.88-76.86 % (*P. sajor-caju*), dan 62.88% (*Lentinula edodes*). Sedangkan rata-rata hasil panen jamur pada media hati batang aren yaitu 210g (*P. ostreatus*), 368g (*P. flabellatus*), 331g (*P. sajor-caju*), dan 48g (*Auricularia polytricha*); sedangkan *P. cystidiosus* dan *L. edodes* tidak dapat tumbuh pada hati batang aren.

Kata kunci: Efisiensi konversi biologi, hati batang aren, jamur, media, serbuk gergaji kayu

UDC/ODC 630*232

I.L.G. Nurtjahjaningsih

PARENT IDENTIFICATION IN A MULTI LOCATION TRIAL SEED ORCHARD OF *Acacia mangium* USING MICROSATELLITE MARKERS

(IDENTIFIKASI TETUA DI KEBUN BENIH UJI MULTI-LOKASI *Acacia mangium* MENGGUNAKAN PENANDA MIKROSATELIT)

Varisi kontribusi gamet pasangan tetua di sebuah kebun benih berakibat pada karakter pertumbuhan anakan yang dihasilkan. Tulisan ini mempelajari kepastian status sistem perkawinan dan untuk mengidentifikasi pasangan tetua yang menghasilakan tampilan pertumbuhan yang bagus pada anakan yang dihasilkan dari kebun benih semai jenis *Acacia mangium*. Penelitian ini dilakukan di dua kebun benih yaitu kebun benih semai generasi pertama (*F1 SSO*) *A. mangium*, sebagai populasi tetua, dan kebun benih uji multi-lokasi (*MLT*), sebagai populasi anakan. Berdasarkan sepuluh penanda mikrosatelit, sistem perkawinan di *F1 SSO* menunjukkan kondisi acak dan seimbang. Pohon dengan pertumbuhan bagus di *MLT* berasal dari variasi kontribusi gamet tetua di *F1 SSO*. Beberapa variasi tersebut yaitu a). pohon terbaik di *MLT* didominasi oleh perkawinan sepasang tetua jantan dan betina di *F1 SSO*; b). satu pohon tetua betina diserbuki oleh dua pohon tetua jantan; c). satu pohon tetua jantan menyerbuki beberapa pohon tetua jantan. Pembungaan serempak dan kecocokan genetik antar pohon menyebabkan terjadinya variasi sistem perkawinan tersebut. Untuk memaksimalkan produksi benih, studi mengenai karakteristik pembungaan jantan dan betina harus dilakukan untuk mengetahui keserempakan pembungaan di kebun benih.

Kata kunci: Identifikasi tetua, kebun benih semai, uji multi-lokasi, mikrosatelit

UDC/ODC 630*31:561

Teguh Setyaji, Sri Sunarti and Arif Nirsatmanto

EARLY GROWTH AND STAND VOLUME PRODUCTIVITY OF SELECTED CLONES OF *Eucalyptus pellita*

(PERTUMBUHAN AWAL DAN PRODUKTIVITAS VOLUME

TEGAKAN KLON *Eucalyptus pellita* TERPILIH)

Dengan menggunakan teknologi terkini, beberapa perusahaan HTI di Indonesia mengedepankan program perhutanan klon *E.pellita* untuk meningkatkan produktivitas tanaman melalui penggunaan klon-klon terpilih. Penelitian ini bertujuan untuk mengevaluasi pertumbuhan awal dan produktivitas volume tegakan klon *E. pellita* terpilih sebagai bagian dari program pemuliaan kayu pulp. Dua uji klon *E. pellita* telah dibangun di Jawa Tengah dengan konfigurasi plot yang berbeda: plot dengan pohon tunggal dan plot dengan banyak pohon. Evaluasi dilakukan pada umur dua tahun pada sifat tinggi pohon, diameter, volume batang dan volume tegakan. Penelitian menunjukkan adanya perbedaan yang signifikan diantara klon yang diuji pada seluruh sifat yang diamati. Seluruh klon yang diuji lebih baik dibanding kontrol yang berupa tanaman yang berasal dari benih F-1, dengan peningkatan 9-50% pada tinggi, 10-36% pada diameter dan 22-137% pada volume batang. Repeatabilitas klonal berkisar 0,7-0,9 dengan repeatabilitas ramet individual berkisar 0,2-0,4. Secara keseluruhan produktivitas volume tegakan pada umur tersebut mencapai 15 m^3/ha.

Kata kunci: *Eucalyptus pellita*, klon, perhutanan klonal, pertumbuhan, volume tegakan

UDC/ODC 630*831

Ari Rakatama

IMPACTS, PATTERNS, INFLUENCING FACTORS AND POLICIES OF FUELWOOD EXTRACTION IN WAY KAMBAS NATIONAL PARK, INDONESIA

(DAMPAK, POLA, FAKTOR YANG BERPENGARUH, DAN KEBIJAKAN PEMANFAATAN KAYU BAKAR DI TAMAN NASIONAL WAY KAMBAS)

Pamanfaatan kayu bakar dari hutan konservasi, seperti Taman Nasional Way Kambas (TNWK), dapat mengancam keberadaan hutan apabila dilakukan tanpa kontrol yang baik. Tulisan ini mempelajari cara mengatasi degradasi hutan di TNWK, dengan dampak negatif minimal bagi masyarakat lokal. Metode penelitian meliputi analisis data dan peta TNWK terkait dengan degradasi hutan, inventarisasi, analisis kebijakan saat ini, survei pengambilan kayu bakar, pengamatan terhadap pengumpul kayu bakar, survei permintaan kayu bakar, dan identifikasi pilihan kebijakan selanjutnya. Hasil penelitian menunjukkan bahwa faktor yang paling signifikan mempengaruhi aktivitas ekstraksi kayu bakar di TNWK adalah kepemilikan tanah, diikuti oleh jarak ke kawasan hutan, tingkat pendapatan, jumlah anggota rumah tangga, dan usia kepala rumah tangga. Aktivitas pemungutan kayu bakar ini terjadi di kawasan TNWK, meskipun dilarang oleh peraturan formal di tingkat nasional, sehingga prinsip pengambilan kayu bakar secara berkelanjutan harus kurang dari 2,89 ton/ha/tahun (pertumbuhan rata-rata tahunan hutan TNWK dalam kondisi normal). Fakta bahwa pengambilan kayu bakar di TNWK menurunkan stok biomasa hutan (1,06 ton/ha/tahun) dan menurunkan indeks keanekaragaman jenis (dari 3,05 menjadi 2,45), indeks kerataan jenis (dari 1,06 menjadi 0,91), dan rasio pohon-permudaan (dari 1,29 menjadi 1). Penurunan kualitas ekosistem disebabkan karena penggunaan teknik yang merusak seperti meranting, menderes, dan menebang. Oleh karena itu, beberapa pilihan kebijakan yang direkomendasikan adalah melegalisasi pengambilan kayu bakar dengan batasan-batasan tertentu, menyediakan sumber alternatif kayu bakar dan energi biomassa lain di luar kawasan TNWK, melakukan upaya pencegahan (mendirikan pos-pos pemeriksaan dan meningkatkan patroli) dan pre-emptive (mendidik dan berkampanye), bekerja sama dengan pemangku kepentingan lainnya, dan memberdayakan ekonomi lokal.

Kata kunci: Kayu bakar, taman nasional, ekstraksi hutan, deforestasi, energi pedesaan

UDC/ODC 630*52

Haruni Krisnawati

A COMPATIBLE ESTIMATION MODEL OF STEM VOLUME AND TAPER FOR *Acacia mangium* Willd. PLANTATIONS

(MODEL YANG KOMPATIBEL UNTUK PENDUGAAN VOLUME DAN TAPER BATANG HUTAN TANAMAN *Acacia mangium* Willd.)

Tulisan ini mempelajari penyusunan model penduga volume yang kompatibel untuk jenis *Acacia mangium* Willd. berdasarkan data dari 279 pohon contoh yang ditebang dari areal tegakan hutan tanaman *A. mangium* di Sumatera Selatan, Indonesia. Model ini terdiri dari model volume total dan model taper batang, yang kompatibel dalam arti volume total yang diperoleh dari integrasi model taper sama dengan volume yang dihitung dengan model volume total. Beberapa fungsi persamaan umum volume total diuji, termasuk faktor bentuk konstan, variabel gabungan, variabel gabungan umum, logaritmik, logaritmik umum dan variabel Honer yang ditransformasi. Hasil pengujian menunjukkan bahwa model logaritmik merupakan model terbaik dan dipilih sebagai dasar untuk menurunkan model taper. Prosedur statistik yang sesuai digunakan dalam penyusunan model untuk mengatasi masalah heteroskedastisitas dan autokorelasi yang berkaitan dengan fungsi persamaan volume dan taper. Metode fitting secara simultan dari seemingly unrelated regression (SUR) menghasilkan estimasi parameter dan statistik kelayakan model yang lebih baik dibandingkan dengan metode fitting secara independen dengan tetap menjamin konsistensi numerik diantara model-model komponen dan mengurangi total kuadrat error. Model yang dikembangkan dapat digunakan untuk menduga volume batang total, volume kayu komersial sampai ke batas diameter tertentu yang dapat diperdagangkan, diameter pada setiap ketinggian, dan (memungkinkan) tinggi dari setiap diameter, hanya berdasarkan parameter yang mudah terukur seperti diameter setinggi dada dan tinggi pohon total untuk jenis yang dianalisis.

Kata kunci: *Acacia mangium*, volume kayu, model pendugaan, volume yang kompatibel, taper

EFFECT OF PIPERONYL BUTOXIDE AND SILVER NITRATE ON DEGRADATION PATHWAYS OF N-OCTADECANE BY *Fusarium* sp. F092

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EFFECT OF PIPERONYL BUTOXIDE AND SILVER NITRATE ON DEGRADATION PATHWAYS OF N-OCTADECANE BY *Fusarium* sp. F092. The aliphatic fraction is usually the largest component in crude oil. Its removal from oil contaminated fields has become an environmental priority and been considered useful for enhancing environmental recovery. Our previous studies reported the isolation of *Fusarium* sp. F092 based on its ability to degrade chrysene. F092 could also degrade crude oils and their aliphatic fractions. However, aliphatic degradation pathways in crude oil have not been clearly understood. The identification of aliphatic metabolite pathways using a representative compound *n*-octadecane was carried out in this study, as well as the effect of Piperonyl Butoxide (PB) and Silver Nitrate ($AgNO_3$) on the degradation of n-octadecane and its metabolite. *Fusarium* sp. F092 had ability to break down *n*-octadecane from about 125 to 13 mg L^{-1} after 60 days incubation. During degradation, several metabolite products could be detected and identified to form carboxylic acid groups. By the addition of PB and $AgNO_3$, inhibitor of monooxygenase and dioxygenase enzymes, *Fusarium* sp. F092 had ability to convert *n*-octadecane to form alkyl hydroperoxides via terminal oxidation pathway with involvement of a dioxygenase.

Keywords: *n*-Octadecane, aliphatic, biodegradation, metabolites product, enzymes, *Fusarium* sp. F092

PENGARUH PIPERONIL DAN PERAK NITRAT DALAM JALUR PENGURAIAN n-OKTADEKANA OLEH Fusarium sp. *F092. Susunan senyawa yang paling besar terdapat di minyak mentah adalah senyawa alifatik. Remediasi senyawa alifatik pada areal terkontaminasi minyak mentah menjadi perhatian utama masalah lingkungan dan bisa menjadi tolak ukur dalam upaya pemulihan areal tercemar. Penelitian sebelumnya menemukan bahwa jamur* Fusarium sp. *F092 mampu mengurai chrysene dan senyawa alifatik yang menjadi penyusun ceceran minyak mentah. Akan tetapi khusus untuk penguraian senyawa alifatik, mekanisme jalur degradasi oleh F092 belum terungkap secara jelas. Penelitian ini bertujuan untuk mengidentifikasi mekanisme degradasi senyawa alifatik dengan menggunakan satu senyawa tunggal alifatik n-oktadekana berikut pengaruh pemberian Piperonyl Butoxide (PB) dan Perak Nitrat ($AgNO_3$) dalam penguraian n-oktadekana. Hasil penelitian menunjukkan bahwa* Fusarium sp. *F092 mampu mengurai n-oktadekana dari konsentrasi awal 125 mg L^{-1} menjadi 13 mg L^{-1} selama 60 hari masa inkubasi. Beberapa senyawa metabolit hasil penguraian dapat terdeteksi dan teridentifikasi sebagai kelompok senyawa asam karboksilat. Dengan penambahan PB dan AgNO3 sebagai penghambat aktivitas enzim dioxygenase dan monooxygenase, dapat diketahui bahwa penguraian n-oktadekana oleh* Fusarium sp. *F092 diawali dengan merubah n-oktadekana menjadi alkyl hydroperoxides melalui jalur terminal oksidasi dengan melibatkan enzim dioxygenase.*

Keywords: n-Oktadekana, alifatik, biodegradation, produk metabolit, enzim, Fusarium sp. *F092*

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I. INTRODUCTION

Fungi belonging to the Genus *Fusarium* are widely distributed and could be found in soil, water, air and plants. Tropical forest is well known for its extremely rich biodiversity including fungi and other microorganisms. For example, the highly valuable *Fusarium* sp. found in Indonesian tropical forests has been used as inducer to accelerate agarwood production. Agarwood is a highly valuable resinous material produced by particular tree species such as *Aquilaria* spp. and *Gyrinops* spp. Previous study indicated that one genera of Fusarium, known as *Fusarium* sp. F092 was able to degrade chrysene under saline conditions (Hidayat, Tachibana, & Itoh, 2012), and aliphatic fraction in crude oil (Hidayat & Tachibana, 2012) . Those results revealed that *Fusarium* sp. screened from nature could be utilized for many bio-prospect purposes such as bio-induction and biodegradation. Hence, microorganism collection, isolation and screening from the Indonesian tropical rain forest should be carried out soon as the declining of good tropical rain forest vegetation is clearly visible.

In general, fungi known for their decaying capabilities to wood in the forest by means of enzymatic reaction for the degradation of lignin and cellulose. Some organic pollutants were identical based on some chemical properties as compared to that of lignin and cellulose. By hypal elongation and proper secretion of enzymes, fungi were able to access, attack, degrade and mineralize xenobiotic pollutants such as phenols and chlorinated phenolic compounds, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and other substances in various matrices to innocuous products.

Environmental quality of mangrove and swamp forest ecosystems in Indonesia have been declining because the use of chemical substances in industrialization and the offshore fossil fuel refinery processes which are generating environmental pollutants (Ke, Yu, Wong, & Tam, 2005) In many cases, environmental effects of the chemical substances have serious hazards to human health and need to be degraded after intended uses. Bioremediation and phytoremediation offers a technology to treat the organic pollutants in mangrove forest and its surrounding with a viable, low cost, and widespread use (Erdogan & Karaca, 2011)

As an organic pollutant, the aliphatic fraction is the largest component in fossil fuels. Its removal from contaminated sites has been considered useful for evaluating the successfulness of the bioremediation program (Binazadeh, Karimi, & Li, 2009). Many microorganisms including fungi are known to grow and utilize hydrocarbons in crude oil and derived products (Cerniglia, 1992; Juhasz & Naidu, 2000; Thavasi, Jayalakshmi, Radhakrishnan, & Balasubramanian, 2007; Yemashova et al., 2007; Sarma & Sarma, 2010; Das & Chandran, 2011). Although aliphatic hydrocarbons are easily biodegraded, but long chain and branched-chain hydrocarbons are not (Hasanuzzaman et al., 2007).

In a previous study, *Fusarium* sp. F092 degraded all aliphatic fractions in crude oil (Hidayat & Tachibana, 2012), but the degradation pathways itself has not been understood. The mechanisms on how *Fusarium* sp. F092 could utilize aliphatic fraction in crude oil as carbon and energy sources needs to be further investigated. Degradation process is usually closely relative to the enzyme production, which could be also examined by addition of an inducer or inhibitor for a specific enzyme to the culture (Mori & Kondo, 2002; Tsai & Li, 2007; Mori, Nakamura, & Kondo, 2009). The objectives of this study were: 1) to investigate the capability of *Fusarium* sp. F092 to degrade aliphatic compound in crude oil, *n*-octadecane; 2) to evaluate the effect of enzyme inhibitor, Piperonyl Butoxide (PB) and Silver Nitrate ($AgNO_3$), on the degradation of *n*-octadecane, as well as its metabolite product during the degradation process.

II. MATERIAL AND METHOD

A. Chemicals

n-octadecane ($C_{18}H_{38}$), *n*-hexadecane ($C_{16}H_{34}$), agar, glucose, wakogel S-1 silica gel, and chemicals were obtained from Wako. Co. Ltd (Osaka, Japan). Thin layer chromatography (TLC) aluminium sheets (silica gel 60 F254, 20 cm x 20 cm) were purchased from Merck (Darmstadt, Germany). Synthetic seawater was obtained from Delphis (Osaka, Japan).

B. Microorganisms

Fusarium sp. F092 has been collected and isolated previously (Hidayat et al., 2012). Prior to use, fungi F092 were cultivated on malt extract agar (MEA) medium containing malt extract (20 g L^{-1}), glucose (20 g L^{-1}), agar (20 g L^{-1}), and polypeptone (1 g L^{-1}) at 25°C for several days and then maintained at 4°C.

C. Degradation of *n*-octadecane

Degradation of *n*-octadecane (initial concentration, 0.5 mM) was investigated in a culture liquid medium. *Fusarium* sp. F092 actively growing on agar were placed into each flask culture medium containing Potato Glucose (PG), potato extract 500 g, glucose 20 g, yeast extract 5 g and artificial sea water 35 g (per-liter of H_2O). The inoculated flasks were pre-incubated for 7 days followed by addition of n-octadecane solubilized in dimethylformamide (DMF), T80, and water. After a fixed time (15, 30 and 60 days), the culture flask was acidified with 5 mL of 1 N HCl. The culture was blended at 10000 rpm for 10 minutes and ethyl acetate was extracted 3 times (40 mL). The ethyl acetate extract was dried over anhydrous Na_2SO_4 and evaporated in a vacuum at 40°C. The concentrations of compounds were quantified by gas chromatography (GC-FID Shimadzu 2014) with a TC-5 capillary column (length: 30 m, diameter: 0.24 mm). The carrier helium gas delivered at a constant rate of 1.5 mL/minute with a column pressure of 100 Kpa and interface temperature of 280°C. The temperature program was started at 60°C, and increased by 10°C/minute until the temperature of 280°C was achieved and maintained for 10-20 minutes at the temperature of 280°C to allow late eluting compounds to exit the column. The injection volume was 2 μL and the injector temperature was maintained at 280°C (Hidayat & Tachibana, 2013).

The effect of inhibition of monooxygenase and dioxygenase was determined as reported previously (Tsai & Li, 2007; Mori et al., 2009). The cultures were incubated for 15 days, and the degradation was examined. The molecular structure of metabolites were also evaluated, the dried extracts were methylated with trimethylsilylation (TMS), *N,O*-bis-trimethylsilylacetamide (40μL), and trimethylchlorosilane (40μL) in pyridine (80μL), prior to the GC-MS analysis. The methylated sample and authentic standard were analysed by gas chromatography with a mass spectrometer (GC-MS Shimadzu QP-2010) equipped with a TC-1 column (length: 30 m, diameter: 0.24 mm) as reported by Hidayat and Tachibana (2013).

D. Statistical Analysis

All results are presented as means ± the standard deviation. Data were analysed to establish differences among individual treatments by t-test using SPSS Version 15 for windows.

III. RESULT AND DISCUSSION

The aliphatic fraction is usually the largest component and its removal from contaminated fields has become an environmental priority and been considered useful for enhancing the recovery of the environment. Microbial degraders have been shown to attack crude oil by degrading the short-chain aliphatics and lower-molecular weight aromatic. Other compounds in crude oil such as resin and asphaltenes were more recalcitrant and with low rates of degradation (Atlas, 1981; Lal & Khanna, 1996). *Fusarium* sp. F092 was isolated based on its ability to degrade chrysene under saline conditions and break down the aliphatic fraction in crude oil. However, these aliphatic degradative pathways are not yet clearly understood.

The degradation of *n*-octadecane was evaluated in order to know the mechanisms by which single aliphatics are broken down by

Fusarium sp. F092 in liquid cultures. Degradation of *n*-octadecane was increased by addition of incubation time, from 15 to 30 or 60 days. At the final incubation, F092 degraded 89% of *n*-octadecane (Figure 1).

A. Addition: Effect of Piperonyl Butoxide (PB)

The effect of PB addition to the *Fusarium* sp. F092 cultures is shown in Figure 2. Increasing the PB concentration did not promote *n*-octadecane degradation. The degradation with 0.1 mM and 0.5 mM was 65% and 66% after 15 days, respectively. No significant differences were found in the degradation of n-octadecane by the addition of the PB ($p < 0.05$) compared to control. PB is a cytochrome P-450 monooxygenase inhibitor (Hogdson & Levi, 1998; Mori et al., 2009) and categorized as a group of methylenedioxyphenyl compound. PB inhibit the binding of CO mixed function oxidases to the heme group of cytochrome P-450 and thus cause the loss of the cytochrome P-450 complex (Hogdson & Levi, 1998). Previous literatures explained that the degradation of toxic aromatic groups by cytochrome P-450 monooxygenase involved several reactions including hydroxylation at an unsubstituted position (Mori et al., 2009; Sakaki & Munetsuna, 2010). This study showed no significant different results and indicated that degradation of *n*-octadecane by F092 occurred without involving P-450 monooxygenase.

B. Addition: Effect of Silver Nitrate ($AgNO_3$)

To investigate the effect of $AgNO_3$ on *n*-octadecane degradation, *Fusarium* sp. F092 was incubated in a liquid culture containing 125 mg L^{-1} of *n*-octadecane and two concentrations of $AgNO_3$ (0.1 mM and 0.5 mM). Comparing to the control, degradation decreased significantly at both $AgNO_3$ concentration ($p < 0.05$, Figure 2). $AgNO_3$ is commonly used as an inhibitor of 1,2- and 2,3-dioxygenase (Aoki, 2001; Kim, Song, Kim, Ho, & Oh, 2003). 1,2- and 2,3-dioxygenase requires Fe^{2+} and Fe^{3+} as a non-iron-sulfur cofactor and two conserved histidines and tyrosines (Broderick & O'Halloran, 1991). The inhibitor together with NO and CN^- can bind at the vacant co-ordination site, to form a ternary complex (Bugg, 2003) Dioxygenase also contains cysteines (Kim et al., 2001), where $AgNO_3$ acts as a cysteine inhibitor or reacts with the sulfhydryls in the protein molecule (Aoki, 2001). This result revealed that degradation of *n*-octadecane by F092 occurred by involving dioxygenase.

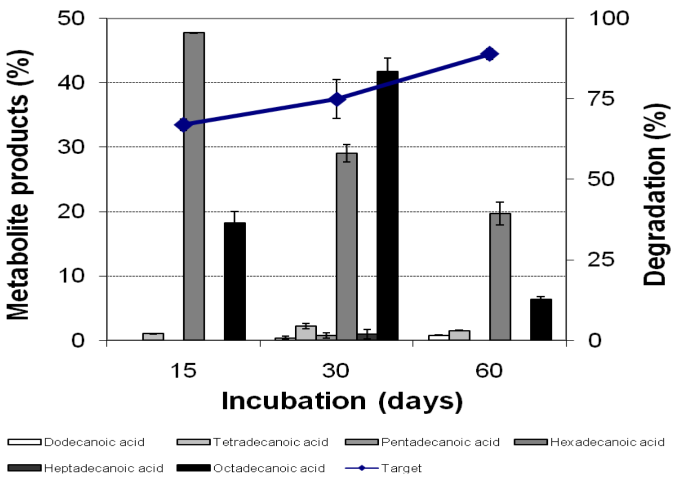

Figure 1. Degradation of *n*-octadecane by F092 and its metabolite products

C. Metabolite Product Degradation of *n*-octadecane

As the result of the degradation, some of metabolite products were detected in control (Figure 1). We found six major metabolites that had been analysed by GC-MS and proven by trimethylsilylation, those are: 1) octadecanoic acid detected at retention time (Rt) of 19.367 and a molecular ion [M^+] at *m/z* 356; 2) heptadecanoic acid having Rt of 18.458, a molecular ion [M^+] at *m/z* 342, and fragmentation ions at *m/z* 327 (M^+ -CH_3) and 269 (M^+ -$Si(CH_3)_3$); 3) hexadecanoic acid found at Rt of 17.508, with a molecular ion [M^+] at m/z 328, and fragmentation ions at *m/z* 313 (M^+ -CH_3) and 255 (M^+ -$Si(CH_3)_3$); 4) pentadexanoic acid had a Rt of 16.508, a molecular ion [M^+] at *m/z* 314, and fragmentation ions at m/z 299 (M^+ -CH_3) and 241 (M^+ -$Si(CH_3)_3$); 5) tetradecanoic acid with Rt of 15.467 and a molecular ion [M^+] at *m/z* 300, fragmentation ions at *m/z* 285 (M^+ -CH_3) and 227 (M^+ -$Si(CH_3)_3$); and 6) dodecanoic acid had a Rtof 13.250, a molecular ion [M^+] at *m/z* 272, and fragmentation ions at *m/z* 257 (M^+ -CH_3) and 199 (M^+ -$Si(CH_3)_3$).

Figure 1 also shows that three of the six metabolites, hexadecanoic acid (47%), octadecanoic acid (18%) and tetradecanoic acid (1%) appeared at 15 days' incubation. After that, two other metabolites were found, pentadecanoic acid (0.7%) and dodecanoic acid (0.3%). However at the end of the incubation, heptadecanoic and pentadecanoic acid had not been detected and the concentrations of the four other metabolites tended to decrease. This fact indicated that F092 were not only able to degrade *n*-octadecane but able to degrade metabolites products also.

The three pathways of *n*-alkanes proposed (Rehm & Reiff, 2005; Harayama, Kishira, Kasai, & Shutsubo, 1999), involving enzyme reactions: (i) terminal oxidation with further separated into; a) monoterminal oxidation ($RCH_3 \rightarrow RCH_2OH \rightarrow RCHO \rightarrow RCOOH$), b) diterminal oxidation ($H_3CRCH_3 \rightarrow H_3CRCH_2OH \rightarrow HOCH_2RCH_2OH \rightarrow HOOCRCOOH$); (ii) subterminal oxidation ($RCH_2CH_3 \rightarrow RCH(OH)CH_3 \rightarrow RC(O)CH_3$) (Rehmn & Reiff, 1981); and (iii) degradation via alky hydroperoxides ($RCH_3 \rightarrow RCH_2.OOH \rightarrow RCO(O)OH \rightarrow RCHO \rightarrow RCOOH$). In case of terminal and subterminal oxidation, *n*-alkane is initially attacked by hydroxylases (monooxygenases) to produce the primary or secondary alcohol. While for the degradation via akyl hydroperoxidase, the enzyme reaction that attacked n-alkane containing FAD^+ and Cu^{2+} categorized as prosthetic group (Maeng

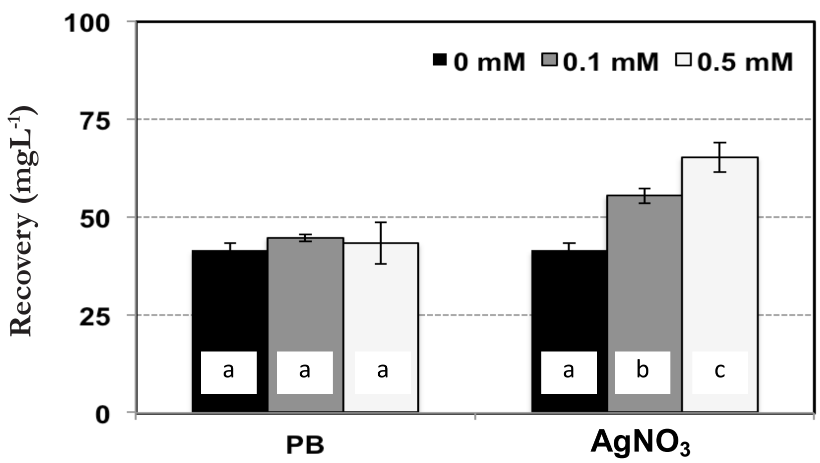

Figure 2. Effect of PB and $AgNO_3$ on recovery of *n*-octadecane after degradation by F092 at 15 day's incubation. The same minor letter on each bar for each treatment is not statistically different from each other (P < 0.05)

was not significantly different from that of control (Figure 2). It means that enzyme P-450 monooxygenase was not involved in the enzyme reaction in the degradation of *n*-octadecane by F092, and the pathway of alkane degradation occurred without terminal or subterminal oxidation. In other way, we also did study via addition of $AgNO_3$ to inhibit the activity of dioxygenase. The *n*-octadecane degradation was via alkyl hydroperoxidases, which might be mediated by a dioxygenase. The route of *n*-octadecane's degradation was initially the formation of octadecyl hydroperoxides, which were further oxidized to produce octadecanal and finally being converted to a fatty acid.

IV. CONCLUSION

Fusarium sp. F092 was identified to have ability in degrading *n*-octadecane and the degradation process was affected by the addition of Piperonyl Butoxide (PB) and Silver Nitrate ($AgNO_3$). During the degradation of *n*-octadecane, some metabolite products were identified by formation of six carboxylic acid groups. The enzymatic reaction also was determined, dioxygenase was recognized as an important enzyme during the degradation process. The degradative pathway of n-octadecane by F092 was done by initially converting *n*-octadecane to form octadecyl peroxides via a dioxygenase and produced carboxylic acid.

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UTILIZATION OF AREN (*Arenga pinnata* Merr.) SAWMILLING WASTE FOR EDIBLE MUSHROOM CULTIVATION MEDIA

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UTILIZATION OF AREN (*Arenga pinnata* Merr.) SAWMILLING WASTE FOR EDIBLE MUSHROOM CULTIVATION MEDIA. Aren (*Arenga pinnata* Merr.) is a multipurpose tree that can be utilized for palm sugar, alcoholic drinks, beverages and construction wood. The use of aren sawdust has not been studied intensively. This study examines the utilization of aren sawdust as cultivation media for edible mushrooms. Aren sawdust was mixed with rice bran, $CaCO_3$, gypsum, fertilizers and distilled water before sterilization in 30 minutes pressurized autoclave at 121°C and 1.5atm. The mixed media was inoculated with pure cultures containing four mushrooms species (*Pleurotus flabellatus*, *P. ostreatus*, *P. sajor-caju* and *Lentinula edodes*) and incubated for five weeks to allow mycelium growth producing fruit bodies. The fruit bodies were harvested everyday within four months and examined for its gained mushroom-weight and biological conversion efficiency/BE. The core part of aren trunk was cut into smaller pieces of 10 cm (width) by 5 cm (thickness), by 120 cm (length). Each core sample was bored from the surface inward, creating holes with a particular distance apart. Each hole was inoculated with pure cultures containing 6 mushroom species (four species above, *P. cystidiosus* and *Auricularia polytricha*). The inoculated samples were slanted on bamboo support, and placed in a bamboo hut. Harvesting was carried out everyday after the fruiting body became mature and examined for its gained mushroom weight. Results show that the use of sawdust supplemented with nutritious material is more likely to improve the mushroom yield than that of aren sawn-timber core. In this case, the BE values with aren-sawdust media were 21.97-89.45% (*P. flabellatus*), 15.36-105.36% (*P. ostreatus*), 63.88-76.86% (*P. sajor-caju*), and up to 62.88% (*L. edodes*). Meanwhile, the yields (gained mushroom weight) with aren sawn-timber media were 210g (*P. ostreatus*), 368g (*P. flabellatus*), 331g (*P. sajor-caju*) and 48g (*A. polytricha*); however, *P. cystidiosus* and *L. edodes* inoculated on aren stem core failed to grow.

Keywords: Aren core, biological conversion efficiency, medium, mushroom, sawdust

*PEMANFAATAN LIMBAH PENGGERGAJIAN KAYU AREN (*Arenga pinnata *Merr.) UNTUK MEDIA BUDIDAYA JAMUR KAYU YANG DAPAT DIMAKAN. Aren (*Arenga pinnata *Merr.) termasuk ke dalam kelompok pohon serbaguna: niranya dibuat gula dan minuman beralkohol, buahnya untuk cocktail, kayunya untuk kostruksi bangunan. Studi pemanfaatan serbuk gergajian kayu aren belum dilakukan secara intensif. Penelitian ini bertujuan untuk mengkaji pemanfaatan serbuk gergajian kayu aren untuk media budidaya jamur kayu yang dapat dimakan. Serbuk gergajian kayu aren dicampur dengan dedak,* $CaCO_3$*, gypsum, pupuk dan air suling dengan komposisi tertentu kemudian disterilkan dengan autoklaf selama 30 menit pada suhu 121°C dan tekanan 1,5 atmosfer. Setelah dingin, kantong-kantong media dibagi 4 kelompok, masing-masing diinokulasi dengan biakan murni empat jenis jamur, yaitu:* Pleurotus flabellatus, P. ostreatus, P. sajor-caju, *dan* Lentinula edodes *kemudian diinkubasikan selama kurang lebih lima minggu untuk memberi kesempatan tumbuhnya miselium membentuk tubuh buah jamur. Jamur dipanen setiap hari selama tubuh buahnya tumbuh sampai sekitar 4 bulan. Data hasil panen per kantong media diakumulasikan kemudian dihitung nilai efisiensi konversi biologinya (EB). Selain itu, limbah berupa hati batang aren dibuat contoh uji dengan ukuran lebar 10 cm, tebal 5 cm dan panjang 120 cm. Contoh uji dilubangi dengan bor pada jarak tertentu, kemudian ke dalam setiap lubang diinokulasi biakan murni 6 jenis jamur yaitu 4 jenis sama seperti pada media serbuk gergajian ditambah dua jenis yaitu* P. cystidiosus, *dan* Auricularia polytricha. *Contoh uji yang sudah diinokulasi jamur disandarkan sedemikian rupa di dalam*

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*gubug bambu. Panen jamur dilakukan setiap hari setelah tubuh buah masak petik. Seperti halnya pada serbuk gergajian, hasil panen jamur ditimbang. Hasilnya menunjukkan bahwa penggunaan media dari serbuk gergajian kayu aren yang mengandung suplemen lebih baik dibandingkan dengan media hati batang aren. Nilai EB pada media dari serbuk gergajian kayu aren yaitu 21,97-89,45 % (*Pleurotus flabellatus*), 15,36-105,36 % (*P. ostreatus*), 63,88-76,86 % (*P. sajor-caju*), dan 62,88% (*L. edodes*). Sedangkan rata-rata hasil panen jamur pada media hati batang aren yaitu 210g (*P. ostreatus*), 368g (*P. flabellatus*), 331g (*P. sajor-caju*), dan 48g (*A. polytricha*); sedangkan* P. cystidiosus *dan* L. edodes *tidak dapat tumbuh pada hati batang aren.*

Kata kunci: *Efisiensi konversi biologi, hati batang aren, jamur, media, serbuk gergaji kayu*

I. INTRODUCTION

Aren (*Arenga pinnata* Merr.) is a multipurpose tree which all parts of this plant can be utilized for various products. The stem can be used for construction, *injuk* (base of leaves petiole in the form of black hairy fibers or the so-called thatch), young leaves, sago starch extracted rom the pith, *nira* (sweet juicy liquid tapped from the flower) and *kolang-kaling* (young fleshy fruit). Its root can be utilized for webbing materials and whipping stuffs; palm pith can be eaten as vegetable; the rib of leaf can be used as brooms and baskets; the young leaves are as substitute for cigarette paper or used as thatching or roofing for housing; and *injuk* fibers (taken from the base of petioles) are used in the manufacture of brushes, brooms and ropes. The flower produce sap or *aren* juice, often called as *nira* that can be used for alcoholic drink, vinegar and sugar. The young *aren* fruit, which is called *kolang-kaling*, usually used for cocktail (Lempang, 2012).

In term of sap production, the plant productive age is Aren trees begin in flower at 12-16 years of age and the tapping of the sap (*nira*) can be carried out for another 3-5 years. Afterwards, the sap tapping is no longer economical, and the unproductive trees will die gradually, thereby leaving behind some particular parts as wastes such as stems, leaves and *injuk* fibers. As the trees get older, they someday become unproductive for such, leaving behind also among others their trunks abundantly which can be utilized for timber or other building component. Unfortunately, such usages generate also enormous wastes, i.e. aren sawdust and sawn-timber cores. Therefore, those wastes are necessary to be used optimally. The hollowed stem is usually used for water-conducting pipe, and its core can be extracted for sago (Heyne, 1987). The outer layer or periphery of aren stem is very hard, and it can be used for housing component, floorings, stairs, poles and agricultural tool handles. Recovery of such products (items) from the sawmilling of aren stem (trunk) is around 13.48% (Rachman, Rohadi, & Balfas, 1989). The rest resulting from that activity revealed that as much approximately 86.52% of aren stems is generated as sawdust and aren core. The possibility of utilization of those wastes for mushroom cultivation can hopefully accelerate their destroying (degrading) process into the compost. Concurrently, this process produces fruit bodies of edible mushroom. Chemical analysis showed that the periphery part of aren stem consists of cellulose 21.69%, lignin 33.76%, pentosan 19.60%, ash 1.40% and silica 0.52%. Meanwhile, the central part (aren core) contains cellulose 44.83%, lignin 36.78%, pentosan 16.58%, ash 4.34% and silica 1.32% (Gusmailina & Hartoyo, 1989). In relevant, this paper scrutinizes the trial results regarding the possible utilization of wastes from aren sawmilling (i.e. aren sawdust and aren core) as the cultivation medium for edible mushrooms.

II. MATERIAL AND METHOD

A. Materials

The main materials used as the cultivation media for edible mushrooms comprised of aren sawdust and aren core. They were collected and taken from the sawmilling laboratory of Forest

Products Research and Development Center as a waste. Mushrooms spawn comprised of pure culture in agar medium and spawn cultured in wood sawdust of sengon (*Falcataria moluccana* (L.) Nielsen).

The activities of this research consisted of two experiments as follows:

B. Methods

1. Trial I: Cultivation on sawdust

Mushrooms cultivation was done under natural room condition (with temperature 22-31°C, and rH 74-95%) in the laboratory of Mycology Forest Products Research and Development Center. Aren sawdust samples as used for the cultivation media of edible mushroom were each added (mixed) with other supplement stuffs, comprising rice bran, gypsum ($CaSO_42H_2O$), fertilizers [ammonium sulphate/ZA($(NH_4)2SO_4$)), urea (CH_4N_2O), NPK/Nitrogen phosphorus (P_2O_5) and potassium (K_2O), trisuperphosphate/TSP $Ca(H_2PO_4)2H_2O$), and potassium chloride/ KCl], and distilled water, with the particular compositions (A, B, C and D) as follows:

A: sawdust 95-75% + rice bran 5-25% + sufficient amount of distilled water.

B: sawdust 84.5-82.5% + rice bran 15% +$CaCO_3$ 0.5-2.5% + sufficient amount of distilled water

C: sawdust 84.5-82.5% + rice bran 15% +gypsum 0.5-2.5% + sufficient amount of distilled water

D: sawdust 77.5% + rice bran 20% + $CaCO_3$ 2% + fertilizers 0.5% + sufficient distilled water

The amount of distilled water as added was 100 to 120% per dry weight of stuffs (materials). The already prepared media were placed into a PVC (polyvinyl chloride) plastic bag with the total weight of 500 grams for each, prior to their sterilization in an autoclave. The sterilized media with the composition A and D were then each inoculated by pure cultures each comprising consecutively white oyster mushroom (*Pleurotus ostreatus*), pink oyster mushroom (*P. flabellatus*), grey oyster mushroom (*P. sajor-caju*) and shiitake (*Lentinula edodes*; originated from Japan). Meanwhile, composition B and C were each inoculated by *P. ostreatus* and *P. flabellatus*. All the inoculated media were then incubated until the mycelium growth (white fibrous formation) from the mushroom partially became well distributed. Each of the treatments (A, B, C, D) was made of five subsamples, further regarded as replicates. Harvesting of mushrooms was carried out every day (and weighed) after the fruiting body of the cultivated mushroom was mature, which lasted for four months' observations.

2. Trial II: Cultivation on aren core

The cultivation media were each prepared from the samples aren core's sawn timber which dimension of 10 cm (width) by 5 cm (thick) by 120 cm (length). Each of the core samples was bored on its surface by a hand driller thereby creating holes inward, each with 1.27 cm in diameter and 2 cm in depth. Each of the holes was prepared by a 15 to 20 cm in distance apart. Inoculations by mushrooms spawn cultured in wood sawdust were carried out into each hole until the hole was full of spawn and gently compacted. Six mushroom species were tested, i.e. by *Pleurotus ostreatus*, *P. flabellatus*, *P. sajor-caju*, *P. cystidiosus*, *Auricularia polytricha* (ears mushrooms) and *Lentinula edodes* (origin from Japan and Kalimantan), whereby each species was inoculated on ten samples as replications. The inoculated samples were then slanted on bamboo support with an angle of ± 60°, placed in a 1.5 m by 2.0 m bamboo hut and located at Bogor. In order to keep moist the environment, the samples were watered twice every day. The further staged procedures on the samples as the media for mushroom cultivation were similar to those as implemented on the aren-sawdust samples. Harvesting was carried out every day after the fruiting body became mature, remarked by the edges becoming thin out. Likewise, the harvesting yields were examined for the gained mushroom weight and BE values (Djarwanto & Suprapti, 2010).

C. Data Analysis

The cumulative weighing data (freshly harvested mushrooms) in gram from each of compositions (treatments) were analyzed by a completely randomized design (CRD). The biological conversion efficiency (BE) was calculated as total gained weight of the freshly harvested mushroom divided by the weight of the dried cultivation media, further presented in percentage (Djarwanto & Suprapti, 2010). Likewise, the BE data were also analyzed by a CRD (Steel & Torrie, 1981).

III. RESULT AND DISCUSSION

The data of mushrooms weight and biological conversion efficiency (BE) value on aren sawmilling wastes are presented on Table 1-5.

A. Cultivation of Mushrooms on Aren Sawdust

The growth of mycelium of mushroom on the surface of each cultivation media sample had dispersed evenly one month after mushroom inoculation. Mushrooms of *Pleurotus ostreatus*, *P. flabellatus* and *P. sajor-caju* were already mature for the harvesting of their fruit body on the third day after the primordial growth; however, for *Lentinula edodes* species it took 5-14 days to reach such maturity. Narh et al. (2011), Djarwanto and Suprapti (2001), Suprapti and Djarwanto (2001, 2009) stated that *Pleurotus ostreatus*, *P. flabellatus* and *P. sajor-caju* were already mature for harvesting on 3rd-4th day after the primordial as steadily grown shaped like a pinhead. The first harvesting occurrences for fruiting body of those mushrooms were 30-179 days

Table 1. The averages of mushroom weight of *Pleurotus flabellatus* and biological conversion efficiency (BE) value on aren sawdust media

Treat-ment	Composition of medium [part %]	First harvesting occasion [days]	Weight [g]	Number of pileus	Harvesting frequency [times]	BE [%]
A	S 95 + R 5	69	134.83 d	86.8	4.8	61.93 c
	S 90 + R 10	48	117.67 e	68.0	4.5	51.38 d
	S 85 + R1 5	48	150.33 bc	94.0	5.5	66.24 b
	S 80 + R 20	48	192.50 a	108.2	7.3	83.84 a
	S 75 + R 25	48	140.83 cd	87.0	4.8	60.84 c
B	S 84.5 + R 15 + Ca 0.5	43	132.17 c	78.5	4.8	53.13 c
	S 84 + R 15 + Ca 1	43	170.17 a	101.7	4.5	68.64 a
	S 83.5 + R1 5 + Ca 1.5	43	145.50 b	95.5	5.0	58.49 a
	S 83 + R 15 + Ca 2	43	156.00 ab	84.0	4.5	63.13 ab
	S 82.5 + R 15 + Ca 2.5	43	149.67 b	104.7	5.3	59.97 bc
C	S 84.5 + R 15 + G 0.5	60	70.33 b	49.2	3.8	26.60 b
	S 84 + R 15 + G 1	64	66.50 bc	43.0	4.2	27.36 b
	S 83.5 + R1 5 + G 1.5	65	54.83 c	31.3	3.3	21.96 b
	S 83 + R 15 + G 2	65	65.50 bc	44.7	4.0	26.76 b
	S 82.5 + R 15 + G 2.5	47	106.00 a	71.7	4.5	41.34 a
D	S 77.5 + R 20 + Ca 2 + ZA 0.5	36	203.00 a	160.8	7.3	89.45 a
	S 77.5 + R 20 + Ca 2 + TSP 0.5	36	140.53 b	124.7	5.3	61.84 b
	S 77.5 + R 20 + Ca 2 + NPK 0.5	42	195.67 a	139.8	6.3	84.66 a
	S 77.5 + R 20 + Ca 2 + KCl 0.5	43	150.67 b	115.0	5.5	64.99 b
	S 77.5 + R 20 + Ca 2 + urea 0.5	30	200.50 a	116.2	6.3	87.15 a

Remarks: ^{S}Sawdust, Rrice bran, $^{Ca}CaCO_3$, ^{G}gypsum, ^{KCl}Potassium Chloride, ^{ZA}ammonium sulphate, ^{TSP}trisuperphosphate, N^{PK}nitrogen phosphorus potassium. Numbers within each a column followed by the same letter, mean non significantly different, Tukey test ($P \leq 0.05$)

Table 2. The averages of mushroom weight of *Pleurotus ostreatus* and biological conversion efficiency (BE) value on aren sawdust media

Treat-ment	Composition of media [%]	First harvesting occasion [days]	Weight [g]	Number of pileus	Harvesting frequency [times]	BE [%]
A	S 95 + R 5	69	35.5 c	6.2	1.6	15.36 c
	S 90 + R 10	54	39.5 c	12.0	1.5	16.96 c
	S 85 + R1 5	53	69.5 b	19.3	1.8	29.98 b
	S 80 + R 20	50	63.5 b	22.2	1.8	27.01 b
	S 75 + R 25	52	112.67 a	33.2	3.3	51.30 a
B	S 84.5 + R 15 + Ca 0.5	44	151.33 b	41.3	3.0	59.83 b
	S 84 + R 15 + Ca 1	44	157.67 b	55.7	3.2	62.33 b
	S 83.5 + R1 5 + Ca 1.5	46	191.00 a	66.3	3.8	75.63 a
	S 83 + R 15 + Ca 2	44	149.33 b	54.0	2.8	59.53 b
	S 82.5 + R 15 + Ca 2.5	44	153.67 b	46.2	3.0	61.06 b
C	S 84.5 + R 15 + G 0.5	44	184.67 a	56.7	5.3	79.28 a
	S 84 + R 15 + G 1	42	200.67 a	48.8	5.8	85.62 a
	S 83.5 + R1 5 + G 1.5	41	196.33 a	61.3	5.7	84.16 a
	S 83 + R 15 + G 2	42	199.13 a	60.5	5.8	84.43 a
	S 82.5 + R 15 + G 2.5	44	200,67 a	64.7	5.2	87.23 a
D	S 77.5% + R 20 + Ca 2 + ZA 0.5	37	210.67 ab	58.7	5.7	91.43 ab
	S 77.5 + R 20 + Ca 2 + TSP 0.5	37	163.17 b	53.7	5.6	78.04 b
	S 77.5 + R 20 + Ca 2 + NPK 0.5	37	239.83 a	80.5	6.7	105.05 a
	S 77.5 + R 20 + Ca 2 + KCl 0.5	37	194.00 ab	41.0	5.0	83.55 ab
	S 77.5 + R 20 + Ca 2 + urea 0.5	37	237.00 a	102.2	5.7	102.38 ab

Remarks: ^{S}Sawdust, ^{R}rice bran, $^{Ca}CaCO_3$, ^{G}gypsum. Numbers within each a column followed by the same letter, mean non significantly different, Tukey test (P<0.05)

after their inoculation (Tables 1, 2, 3, and 4). Djarwanto and Suprapti (2001), and Djarwanto, Yamto and Roliadi (2004) reported that the initial harvest occasions of oyster mushrooms were around 26-51 days (for *P. ostreatus*), 26-30 days *P. flabellatus*, 36-61 days (*P. sajor-caju*) and 139-150 days (*L. edodes*) after their inoculation. Shah, Ashraf and Ishtiaq (2004) stated that the fruiting body of P. ostreatus could be harvested about 27-34 days after inoculation. Djarwanto and Suprapti (2001) reported that the first harvesting of *L. edodes* was about 93-194 days after inoculation. The mushroom yield, harvesting frequency, and BE value are presented at Table 1 (for *P. flabellatus*), Table 2 (*P. ostreatus*), Table 3 (*P. sajor-caju*), and Table 4 (*L. edodes*). According to statistical analysis, supplementation of rice bran, minerals and fertilizers was generally significantly influencing the mushroom weight and BE value ($p \leq 0.05$).

Concerning the rice bran supplementation (incorporation) on media, the highest yield (with respect to the weight and BE values) could be reached with rice bran percentages as much as consecutively 20% (*P. flabellatus*), 25% (*P. ostreatus*), 10% (*P. sajor-caju*), 10% and 20% (*L. edodes*), as shown on Tables 1, 2, 3, 4. Suprapti (1988) reported that rice bran supplementation as much as 10-20% did not significantly affect the yield. The lowest yield was found on the media with 5% rice bran. The average yields on the media with rice bran supplementation were 147.23 grams (*P. flabellatus*), 64.13 grams (*P. ostreatus*), 140.50 grams (*P. sajor-caju*), and 65.80 grams (*L. edodes*). Such low yield values were caused by the developing failure and wilting of the primordial. The averages of the BE values were 68.41% (*P. flabellatus*), 28.81 % (*P. ostreatus*), 65.85% (*P. sajor-caju*), and 36.41% (*L. edodes*) (Table 1, 2, 3, 4). The BE value of

Table 3. The averages of mushroom weight of *Pleurotus sajor-caju* and biological conversion efficiency (BE) value on aren sawdust media

Treat-ment	Composition of media [%]	First harvesting occasion [days]	Weight [g]	Number of pileus	Harvesting frequency [times]	BE [%]
A	S 95 + R 5	64	112.6 b	22.2	5.0	66.74 a
	S 90 + R 10	64	146.4 a	27.4	5.2	68.60 a
	S 85 + R1 5	103	137.0 a	22.6	5.4	64.11 a
	S 80 + R 20	110	136.2 a	25.6	4.8	63.88 a
D	S 77.5 + R 20 + Ca 2 + ZA 0.5	107	145.2 ab	28.8	4.6	72.81 a
	S 77.5 + R 20 + Ca 2 + TSP 0.5	114	152.6 ab	26.2	5.8	76.86 a
	S 77.5 + R 20 + Ca 2 + NPK 0.5	69	145.6 ab	24.6	5.0	67.95 ab
	S 77.5 + R 20 + Ca 2 + KCl 0.5	129	112.2 c	20.4	3.4	56.07 b
	S 77.5 + R 20 + Ca 2 + urea 0.5	114	129.2 bc	23.0	5.8	76.56 a

Remarks: [S]Sawdust, [R]rice bran, [Ca]$CaCO_3$, [G]gypsum. Numbers within each a column followed by the same letter, mean non significantly different, Tukey test ($P \leq 0.05$)

Table 4. The average mushroom weight of *Lentinula edodes* and biological conversion efficiency (BE) value on aren sawdust media

Treat-ment	Composition of media [%]	First harvesting occasion [days] **	Weight [g]	Number of pileus	Harvesting frequency [times]	BE [%]
A	S 95 + R 5	118	70.0 b	3.8	1,4	30.99 b
	S 90 + R 10	143	71.0 b	3.0	2.0	31.76 b
	S 85 + R1 5	74	146.0 a	6.0	1.0	62.88 a
	S 80 + R 20	143	42.0 c	1.0	1.0	20,02 c
	S 75 + R 25	0*	0* d	0*	0*	0* d
D	S 77.5 + R 20 + Ca 2 + ZA 0.5	138	22.5 b	1.0	2.0	11.28 b
	S 77.5 + R 20 + Ca 2 + TSP 0.5	179	50.0 a	2.0	1.0	25.19 a
	S 77.5 + R 20 + Ca 2 + NPK 0.5	0*	0* c	0*	0*	0* c
	S 77.5 + R 20 + Ca 2 + KCl 0.5	0*	0* c	0*	0*	0* c
	S 77.5 + R 20 + Ca 2 + urea 0.5	0*	0* c	0*	0*	0* c

Remarks: [S]Sawdust, [R]rice bran, [Ca]$CaCO_3$, [G]gypsum. *fruit body rotten and not develop. Numbers within each a column followed by the same letter, mean non significantly different, Tukey test ($P \leq 0.05$)

Table 5. The average mushroom weight on media made of sawn timber of *aren* core

No.	Mushroom species	First harvesting occasion [days] ***	Weight [g]	Number of pileus	Harvesting frequency [times]
1	*P. flabellatus*	43	368.2	591.4	10.8
2	*P. ostreatus*	64	210.3	37.0	4.3
3	*P. sajor-caju*	136	331.5	129.2	5.5
4	*P. cystidiosus*	0*)	0*)	0*)	0*)
5	*A. polytricha*	99.0	48.0	67.0	2.0
6	*L. edodes* (Japan)	0**)	0**)	0**)	0**)
7	*L. edodes* (Kalimantan)	0**)	0**)	0**)	0**)

*)Remarks: Primordium did not develop, **)fruit body did not grow; ***) after mushroom-spawn inoculation

P. ostreatus was generally lower than the value of the previous research results on medium made of sawdust of *Hevea brasiliensis* Muell. Arg. and *Mangifera caesia* Jack. (Suprapti, 1988). Because of insufficient materials, *P. sajor-caju* had not been cultivated on media with 25% rice bran.

Fruit body of *L. edodes* was not found on media with 25% rice bran due to the media rotting and or drying.

$CaCO_3$ supplementation was significantly influencing the *P. flabellatus* and *P. ostreatus* yield ($p<0.05$). It is shown that higher $CaCO_3$ percentage did not always improves or bring about changes on the yield. The highest yields were found on media with $CaCO_3$ percentages at 1% (*P. flabellatus*) and 1.5% (*P. ostreatus*), with BE values reaching 68.64% and 75.63%, respectively (Tables 1, 2). FAO (1982) and Suprapti et al. (1994) stated that the optimum amount of calcium-containing compound to be added into the substrate ranged about 1-2.5%. The average yields (i.e. mushroom weight) on media using $CaCO_3$ supplementation were 150.70 grams (*P. flabellatus*) and 160.60 grams (*P. ostreatus*), with BE values consecutively 60.69% and 63.68%. Those values were still close to the BE values with the same mushroom species but on rubberwood media (Suprapti & Djarwanto, 1990).

Gypsum supplementation on media inoculated with *P. ostreatus* was not significantly influencing the yield ($p<0.05$). The highest yield (mushroom weight) and BE value were found on media with 2.5% gypsum. The average yields from media with gypsum were consecutively 72.63 grams (*P. flabellatus*) and 199.20 grams (*P. ostreatus*); whereas, the corresponding BE value were 28.81% and 84.14%, respectively. Those values were higher than the results of previous research with the same mushroom species but on rubberwood sawdust media (Suprapti & Djarwanto, 1990).

Fertilizers supplementation was generally able to increase the mushroom yield (i.e. weight and BE values), whereby different kinds of fertilizers were significantly influencing the yield ($p<0.05$). The highest yield (mushroom weight) and BE value were found on media with ZA (*P. flabellatus*), NPK (*P. ostreatus*), TSP (*P. sajor-caju* and *L. edodes*) (Tables 1, 2, 3, 4). Fertilizers consisted of among others nitrogen element, which presumably enables them to perform better as media cultivation compared to other medium stuffs. Possibly, such was caused by the nitrogen demand for mycelium growth, so the mushroom's fruit body grows fast. Djarwanto et al. (2004) reported that the nitrogen supplementation would increase the yield. It was found that the average yields (mushroom weight) from media with fertilizers were consecutively 178.03 grams (*P. flabellatus*), 208.93 grams (*P. ostreatus*), 136.96 grams (*P. sajor-caju*), and 14.50 grams (*L. edodes*). Meanwhile, the corresponding BE values are 77.62%, 92.09%, 70.05% and 7.29%, respectively. In the previous research results according to Djarwanto and Suprapti (2001), the BE values were 81.31 % (for *P. flabellatus*), 74.95% (*P. ostreatus*), 86.08% (*P. sajor-caju*). Still related, Shah et al. (2004) and Narh et al. (2011) stated that the BE values of mushrooms for *P. ostreatus* were 62.1-64.7% and 50.9-59.8%. Meanwhile, the corresponding BE values were consecutively 24% for *P. sajor-caju* (Villaceran, 2006), 50.1-70.6% for *P. flabellatus* (Khan et al., 2012), 50.9 % for *P. ostreatus* and 34.5% for *P. sajor-caju* (Obodai et al. (2008). The mushroom yield (i.e. weight and BE values) from *L. edodes* species was very low (Table 4), particularly for the mushrooms which were grown on the media with the incorporation of KCl, NPK, and urea. In this situation, the mushroom primordial (pinhead) failed to develop (dry, wilt and then rotten). Almost all kinds of these media (with KCL, NPK, and urea) seemed unintended for mushroom cultivation,, and the watering treatment through mycelium spaces rendered the mushroom rotten. Djarwanto et al. (2001) reported that the BE value of *L. edodes* was about 3.43-41.01%. Meanwhile, Diehle and Royse (1991) stated that BE values *L. edodes* cultivated on nutrient-enriched maple and birch sawdust were around 139.8-146.3%.

B. Cultivation of Mushroom on Aren Core

In the media of aren core's sawn timber for mushroom cultivation, *Pleurotus ostreatus*, *P. flabellatus* and *P. sajor-caju* were also already mature for harvesting on the third day after the growth of their primordial grown; however, for

Auricularia polytricha, it took about 5-14 days for such harvesting. Based on this research, the fruit body of *A. polytricha* was ready for harvest 5-14 days after its primordial was formed. The mushroom was fully mature when the edge of fruit body thinned out and became wavy, and the mushroom could be easy to pull out. Upadhyay and Sing (2010) reported that the fruit body of *Auricularia* spp. could be harvested on 3rd -7th days by examining the pinhead-like appearance. However, Oei (2005), Kristiawan and Budiana (2011) stated that the primordial need 7-10 days for the mushroom's fruit body to become mature.

The initial harvest occasion of *P. sajor-caju* was 136 days after inoculation, similar to that cultivated on the media of several particular wood species as stated by Suprapti and Djarwanto (2001a) i.e. 93-157 days after inoculation. The initial harvest of *A. polytricha* was 99 days that took longer duration than that of previous research which was 74 days after inoculation. Further, those initial harvest occasions which were much later than that of the previous researches conducted far earlier by Suprapti and Djarwanto (1992, 1998, 2001b), were consecutively 54, 62 and 59 days after the mushroom-spawn inoculation.

The yield of mushrooms (i.e. weight and BE values) cultivated on a piece of aren core media is presented in Table 5. The yield was very low with dwarf (very small) fruit bodies, thereby causing the significant increase in the number of pileus (caps). The harvesting occasion of *P. ostreatus* was the earliest i.e. 43 days after inoculation, whereas the latest was *P. sajor caju* being 136 days after inoculation. Number of the pileus of *Auricularia polytricha* cultivated on a piece of aren core was 67, much more than that of previous research which numbered only 4.0-15.4 and 5.4-15.5 pileus (Onyango et al., 2011), and 1.0-29.3 and 37.6 pileus (Suprapti & Djarwanto, 1992, 1998).

L. edodes mushrooms (i.e. originated from Japan and Kalimantan) were not producing fruit body and only showed the mycelial growth which dispersed and thickened on the surface of aren core. Also, on *P. cystidiosus* mushrooms were only found mycelium and spores that grew on the surface of aren core. Such occurrence was possibly caused by the insufficient food reserves such as potassium, sodium, phosphorous and micro elements. Such elements in amounts were found less in the substrate for the growth of its fruit body.

At the age of four months after mushroom-spawn inoculation, most of the sample media had deteriorated, and the mycelial growth was difficult to continue and thickening not occurred due to the separation of fibers bondage on aren core. As a result, the fruit bodies did not grow at all. Some samples of the inoculated cultivation media (aren core) were found rotten that probably was caused by bacterial infection since there was found some bacterial slimy on it.

IV. CONCLUSION

Two kinds of main stuffs were tested as the cultivation media for edible mushrooms (i.e. aren sawdust and aren stem core's sawn timber). The mushroom species as tested comprised *Pleurotus ostreatus*, *P. flabellatus*, *P. sajor-caju*, *P. cystidiosus*, *Auricularia polytricha* (ears mushrooms) and *Lentinula edodes* (originated from Japan and Kalimantan). It turns out that aren sawdust could be used more favorably for such mushroom-cultivation media. The best growth results of the cultivated mushroom, with respect to the high mushroom yield (i.e. gained fresh weight and biological conversion efficiency/BE values) would be achieved on aren-sawdust media, but added (mixed) with other supplement stuffs that comprised rice bran, $CaCO_3$, gypsum and fertilizers. The proportion of such added stuffs (materials) could vary, such as rice bran 5-20%, $CaCO_3$ 0.5-2.5%, gypsum 0.5-2.5% and fertilizers less than 0.5%. On the other hand, the aren core was strongly indicated as less suitable for the cultivation media of such mushroom species.

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PARENT IDENTIFICATION IN A MULTI LOCATION TRIAL SEED ORCHARD OF *Acacia mangium* USING MICROSATELLITE MARKERS

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PARENT IDENTIFICATION IN A MULTI LOCATION TRIAL SEED ORCHARD OF *Acacia mangium* USING MICROSATELLITE MARKERS. Variation of parent gametes' contribution might affect the growth patterns among offspring produced from seed orchards. This paper studies the mating system statuses and to identify parent trees that produce good growth performance of offspring in seedling seed orchard of *A. mangium*. The study was conducted in two seed orchards, i.e. a first generation seedling seed orchard (F1 SSO) of *A. mangium,* used as the parent population hereafter and a multi location trial (MLT) as an offspring population. Based on 10 microsatellite markers, mating system in the F1 SSO was under panmictic equilibrium condition. The good growth trees in the MLT originated from various parent genes contribution in the F1 SSO. Several behaviors were observed: a). the best trees in MLT dominantly originated from single pair trees, between maternal and paternal trees, in F1 SSO; b). a maternal tree was pollinated by two paternal trees; c). a paternal tree pollinated several maternal trees. Flowering synchronization and genetic compatibility among trees might be responsible for these mating system patterns. In order to maximize seeds production, studies on male and female flowers characteristic should be employed to assess flowering synchronization among individual trees in the seed orchard.

Keywords: Parent identification, seedling seed orchard, multi-location trial, microsatellite

IDENTIFIKASI TETUA DI KEBUN BENIH UJI MULTI-LOKASI Acacia mangium *MENGGUNAKAN PENANDA MIKROSATELIT. Varisi kontribusi gamet pasangan tetua di sebuah kebun benih berakibat pada karakter pertumbuhan anakan yang dihasilkan. Tulisan ini mempelajari kepastian status sistem perkawinan dan untuk mengidentifikasi pasangan tetua yang menghasilakan tampilan pertumbuhan yang bagus pada anakan yang dihasilkan dari kebun benih semai jenis Acacia mangium. Penelitian ini dilakukan di dua kebun benih yaitu kebun benih semai generasi pertama (F1 SSO)* A. mangium*, sebagai populasi tetua, dan kebun benih uji multi-lokasi (MLT), sebagai populasi anakan. Berdasarkan sepuluh penanda mikrosatelit, sistem perkawinan di F1 SSO menunjukkan kondisi acak dan seimbang. Pohon dengan pertumbuhan bagus di MLT berasal dari variasi kontribusi gamet tetua di F1 SSO. Beberapa variasi tersebut yaitu a). pohon terbaik di MLT didominasi oleh perkawinan sepasang tetua jantan dan betina di F1 SSO; b). satu pohon tetua betina diserbuki oleh dua pohon tetua jantan; c). satu pohon tetua jantan menyerbuki beberapa pohon tetua jantan. Pembungaan serempak dan kecocokan genetik antar pohon menyebabkan terjadinya variasi sistem perkawinan tersebut. Untuk memaksimalkan produksi benih, studi mengenai karakteristik pembungaan jantan dan betina harus dilakukan untuk mengetahui keserempakan pembungaan di kebun benih.*

Kata kunci: Identifikasi tetua, kebun benih semai, uji multi-lokasi, mikrosatelit

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I. INTRODUCTION

Acacia mangium is native to Northeastern Queensland (Australia), Western Province of Papua New Guinea (PNG) and Moluccas (Aru Islands, Seram, the Sula Islands) and Irian Jaya (Sidei) of Indonesia (Orwa, Mutua, Kindt, Jamnadass, & Anthony, 2009; Saro, Robledo-Arnuncio, González-Pérez, & Sosa, 2014). It has high economical value for pulp production. This species is dominantly outcrossing with insect pollinators, especially bees and small birds which disperse the seeds (P. Butcher, Harwood, & Quang, 2004; Orwa et al., 2009). In Indonesia, demand for high quality seeds of A. mangium has been increasing, due for use as commercial plantation materials. For this reason, since 1990s a breeding strategy for the species has been established through series of progeny trials to secure production of quality and quantity seeds (Nirsatmanto, Leksono, Kurinobu, & Shiraishi, 2004). The progeny trials had been converted to seed orchards to meet demand of genetically improved seeds for commercial plantations and genetic materials for sequential generations in breeding strategies. Moreover, to test genetic gain and provide more quantity of improved seeds, a multi-location trial had been established, using seeds from the SSO.

To assure the production of high quality seeds from seed orchards, mating system should be under random mating. However, the ideal condition has rarely occurred. High selfing rates and contamination rates from unimproved stand, uneven or unbalanced mating system and variation of parental gametes' contribution have been reported as major problems in reducing quality seeds produced from seed orchard (Dering & Chybicki, 2012; El-Kassaby, Ritland, Fashler, & Devitt, 1988; Moriguchi, Taira, Tani, & Tsumura, 2004; Saro et al., 2014). Various factors influence mating system and pollen contribution mechanism including genetic factors such as flowering phenology synchronization that influence the compatibility between pollen-stigma genes interaction (Larson, Hume, Andres, & Harrison, 2012), mate choices (Maroja, Andres, Walters, & Harrison, 2009) and environmental factors, such as trees density and pollinators that affected to population size (Dow & Ashley, 1998). Many studies reported that one of the reasons in the unbalanced mating system is caused by seed orchards which are encompassed by many provenances which have differences in flowering phenology characteristics (Hansen & Kjaer, 2006).

In case of tree improvement strategy in *A. mangium* in Indonesia, the progeny trial had been converted to seedling seed orchards (called as F1 SSO hereafter). High quality seeds then could be expected from these orchards for plantation programs and genetic materials in sequential strategies including multi location trial seed orchard (called MLT, hereafter). Mating statuses in the SSO have not been assessed yet. Moreover, based on growth performances (DBH x height), selected plus trees in the F1 SSO seem to be mostly uniform with good performances. In contrast, growth performances were more variable among plus trees in MLT, with parent trees originating from the SSO. Identification of parent gametes in F1 SSO that produce good performances in the MLT might be useful to increase efficiency in sequential tree improvement strategies, especially when a clonal seed orchard is going to be established in the near future. To increase production of seeds, the CSO should be composed by mother trees that have value of general combining ability (GCA). Recently, estimation of GCA value could be approached by phenotypic observation in full-sib population, but it is difficult to identify those parents which contributed to the mating system.

Parental analysis using DNA markers provides information accurately on identification of parent gametes contribution. Recent advances in DNA markers, microsatellite or simple sequence repeat (SSR) allow genetic diversity observation in tree species. Microsatellites have 2-6 nucleotide repeat tandem and highly polymorphic allele. Microsatellites enable to detect heterozygote alleles due to co-dominant markers and show bi-parentally inherited markers. The power of microsatellite markers had been proven to identify parents within hybridization zones of *Fraxinus* (Thomasset et al., 2014).

The study aimed to analyze mating system and to identify parent trees that may produce good growth performance offspring in seedling seed orchard of *A. mangium*.

II. MATERIAL AND METHOD

A. Description of Seed Orchards

This study was conducted in two seedling seed orchards (SSOs) of *A. mangium* i.e. a first generation seedling seed orchard (F1 SSO) and a multi location trial seed orchard (MLT). The F1 SSO was used as a parent population and MLT was used as offspring population. The F1 SSO was established in 1994 located in Wonogiri (Central Java). The SSO consisted of 144 families originating from two provenances i.e. Queensland and Papua New Guinea (PNG), that is designed as a single population which consisted of 4 sub-line systems i.e. sub line A and C from Australia; sub-line B and D from PNG. Each family were planted with 4 trees replications and they were replicated in 7 blocks. Initial spacing between trees was 4 x 2 m. The total number of trees was 4,032 trees covering an area of 3.53 Ha. The last selective thinning conducted was in year 2000; thinning eliminated trees and families based on growth characters. The current number of trees is 620. Origin and number of families encompassed by the SSO are shown in Table 1. MLT was established in 2002. It is located near the F1 SSO. MLT encompasses a bulk of 64 open pollinated progenies of the F1 SSO. Parents of the progenies in the MLT were unknown.

B. DNA Extraction and Microsatellite Analysis

DNA was extracted from all trees in F1 SSO as parental population (N=620) and 32 best growth trees in the MLT as offspring population. The number of maternal trees for establishing CSO parental analysis was only based on 32 trees. The extraction was done following CTAB method (Shiraishi & Watanabe, 1995).

Multiplexed polymerase chain reactions (PCR) were developed in this study For the

Table 1. Number of families in the F1 SSO of *Acacia mangium*

Provenance	Population	Number of family	Family composition (%)
QLD	135K	36	6
	Cassowary	45	7
	ClaudieR	114	18
	ClaudieRI	38	6
	ClaudieRE	37	6
	Pascoe	28	5
	Poscoe	18	3
PNG	Arufi	30	5
	Bimadebun	28	5
	Biote	37	6
	Derideri	48	8
	Dimisisi	18	3
	Gubam	52	8
	Kini	46	7
	Wipim	45	7
Total		620	100

amplification, 5 ng DNA was used in the final volume of 10μL AmpliTaq Gold @360 master mix (Applied Biosystem; #ID:4398876). This study used 10 microsatellite loci i.e. Am014, Am136, Am326, Am341, Am387, Am429, Am435, Am460, Am465, and Am503 that developed for *A. mangium* (P. A. Butcher, Decroocq, Gray, & Moran, 2000). PCR involved a de-naturating step of 94oC for 5 min followed by 10 cycles PCR touchdown (94°C for 1 min, touchdown for change 1 min from 65°C till 55oC and 72°C for 1 min), followed by 25 cycles PCR (94°C for 1 min, 55°C for 1.5min and 72°C for 1.5min) and finally one cycle of 72°C for 7 min (Yuskianti & Isoda, 2012).

PCR product was mixed with HiDi Formamide (Applied Biosystem) and ROX 400HD size standard (Applied Biosystem) and denaturated at 95°C for 5 min before the products were analyzed using Gene Analyzer 3100 AVANT (Applied Biosystem). Fragment DNA patterns were analyzed by GeneMapper ver. 2.0 (Applied Biosystem).

C. Parent Identification

As described above this study was based on genotype data of 620 trees in F1 SSO as parental and 32 trees in MLT as offspring. Panmictic condition that estimated mating system status was conducted by comparing genetic diversity parameters between parental and offspring populations i.e. number of detected allele (N_A), expected heterozygosity (H_E), allelic richness (A_R) and coefficient inbreeding (F_{IS}). The AR was calculated with minimum number of samples i.e. 29 samples (58 gene copies) for each locus. The parameters were performed using FSTAT software (Goudet, 2001).

Direct parental analysis was estimated by comparing microsatellite data between 620 trees in F1 SSO and 32 best trees in MLT and calculated using Cervus 3.03 software (Kalinowski, Taper, & Marshall, 2007). Pollen dispersal distances were calculated manually by Pythagoras principles.

III. RESULTS AND DISCUSSION

A. Genetic Diversity within Parental and Offspring Population

Genetic diversity parameters for 10 microsatellite loci in parents and offspring are shown in Table 2. The number of detected alleles (N_A) was 160 in parental and 84 in offspring, respectively. For parental population, value of N_A per locus ranged between 8 and 25, and for offspring the value ranged between 3 and 13. The H_E ranged between 0.591 and 0.872

Table 2. Diversity parameters for six microsatellite loci in parental and offspring populations

Locus name	N		N_A		H_E		$A_{R[58]}$		F_{IS}	
	P	O	P	O	P	O	P	O	P	O
Am014	620	32	22	12	0.872	0.849	15.78	11.89	0.333*	0.007ns
Am136	620	32	20	7	0.820	0.767	10.19	6.98	0.066*	-0.019ns
Am326	620	32	19	13	0.816	0.806	11.52	12.60	0.301*	-0.124ns
Am341	620	32	8	3	0.591	0.415	4.39	3.00	0.227*	-0.012ns
Am387	620	32	15	10	0.814	0.802	8.75	9.74	0.166*	0.115ns
Am429	620	32	15	8	0.804	0.806	8.61	7.81	0.170*	-0.047ns
Am435	620	32	19	7	0.759	0.673	8.96	6.89	0.011ns	0.071ns
Am460	620	32	8	6	0.768	0.805	6.46	6.00	0.271*	0.319*
Am465	620	32	25	10	0.799	0.794	13.91	10.00	0.117*	0.348*
Am503	620	32	9	8	0.726	0.675	6.33	7.87	0.275*	-0.052ns
Mean	620	32	16	8.4	0.777	0.739	9.49	8.28	0.194*	0.066ns

Remarks: P: parental population, O: offspring population, N: number of samples, N_A: number of detected alleles, H_E: expected heterozygosity, A_R[58]: allelic richness, F_{IS}: coefficient inbreeding, level of significance: * $p<0.05$, NS: $p>0.05$

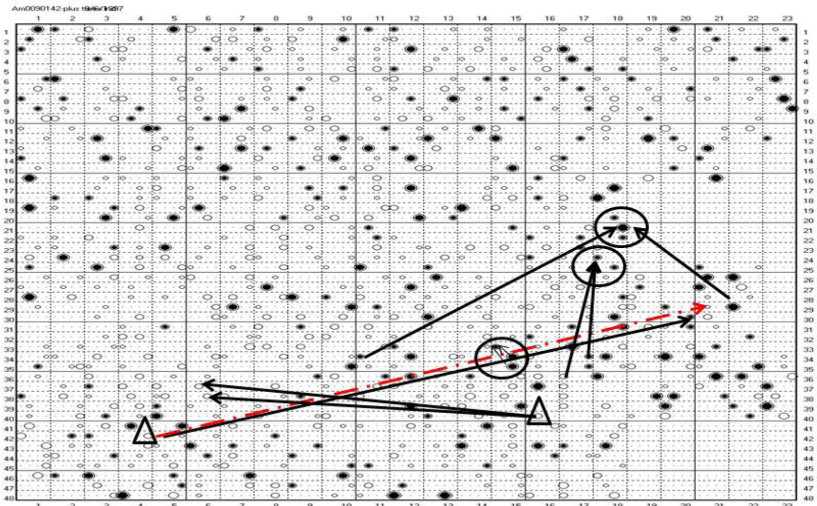

Figure1. Distribution of parent pairs within the SSO single population F1 of *A. mangium*. Arrow with line indicated pollen parents to the maternal trees

Remarks:

: Maximum pollen dispersed; Circles: a female tree pollinated by 2 male trees; Triangle: a male tree pollinated 2 female trees

for parental population, and 0.415 and 0.849 for offspring. The value of A_R ranged between 4.39 and 15.78 for parental population, and 3.00 and 12.60 for offspring. Deviations from Hardy-Weinberg expectations that measured the significant deficiency (F_{IS}) showed statistically high heterozygosity deficit for parental, but the value was insignificant for offspring.

The differences in genetic diversity parameters between parental population and offspring could be used as a mating system indicator within a seed orchard when polymorphism alleles were low (Chaix et al., 2003; Nurtjahjaningsih, Saito, Tsuda & Ide, 2007). Genetic diversity of offspring was higher than parental population under random mating/ panmictic equilibrium condition in seed orchard of *Pinus merkusii* (Nurtjahjaningsih et al., 2007) and *Eucalyptus grandis* (Chaix et al., 2003). The results in this study showed that parameters of genetic diversity in parental and best performer of offsprings were similar. Insignificant value of coefficient inbreeding in offspring population showed that mating system within the SSO was under panmictic equilibrium.

Synchronization flowering phenology is one of the important factors in random mating in order to produce quality and quantity seeds (El-Kassaby, Fashler, & Sziklai, 1984). Genetic variation increase when synchronization of flowering was achieved in Pseudotsuga menziesii seed orchard (El-Kassaby et al., 1998). However, this ideal condition rarely occurred due to differences in provenances/ geographical origins encompassing a seed orchard (Chaix et al., 2003; Moriguchi et al., 2004). Besides, flowering phenology also varied among individual trees or families within provenances (Burczyk & Chalupta, 1997). Unequal flowering phenology cause unbalances in gamete contribution and increase pollen contamination (Chaix et al., 2003; Moriguchi et al., 2004).

B. Parent Identification

Paternal analysis was conducted by comparing directly the genotypes of all trees in F1 SSO and the best 32 trees in the MLT. However to avoid reader misunderstanding, not all parent pairs were shown in the result. Figure 2 showed that, within the SSO, pollination pattern tended to have North direction. The behavior of the pollen donor to each maternal tree seemed to be independent of their position in the SSO.

Nevertheless, distances between the maternal trees and the pollen donor did not seem to have patterns; pollen donor trees could be from neighbor or distant trees. Based on position of paternal trees and maternal trees in the SSO, the distance of pollination ranged between approximately 15 to 150 m. Single pollen donor to the maternal trees seems to be the dominant pollination. However, interestingly, a maternal tree was pollinated by two pollen donor trees. In contrast, a pollen donor had pollinated two or more maternal trees.

Using 10 microsatellite markers, parent trees of plus trees in the MLT of *A. mangium* had been identified. The microsatellite markers has a powerful tool to identify the parent pair in the SSO that was characterized by value of non-exclusion probabilities (NEP:11x10-8). Specific microsatellite loci influence the value of exclusion probabilities (EP) that affect the accuracy of parental analysis (Chaix et al., 2003). Each microsatellite locus has many rare alleles, thus using this marker could be expected to have high value of EP (Dow and Ashley, 1998). A few number of microsatellite with high value of EP (>0.997) considered enough for paternity analysis (Chaix et al., 2003; Moriguchi et al., 2004).

Pollen dispersed randomly within the SSO (Figure 2). Pollen donor trees for each maternal tree seemed to be independent of their position in the SSO. Figure 2 also showed that pollen could be dispersed approximately 150 meters distances (red arrow). Previous study reported that pollen of *A. mangium* could be dispersed by only 40 m (Isoda, Yuskianti, & Rimbawanto, 2002). This distance was smaller than pollen contamination rate in *Eucalyptus grandis* seed orchard due to it was pollinated by another *E. grandis* planting test that was located 400 m away and one kilometer of *E. robusta*, respectively (Chaix et al., 2003). Moreover, pollen in coniferous species such as Pinus sylvestris could be dispersed within 30 km (Robledo-Arnuncio & Gill, 2005). Capability of dispersed pollen contributes to the design of the SSO. Pollen flow to the maternal tree might be affected by several factors. Individual trees which originate from same provenance expected to have similar pattern in flowering phenology (Burczyk & Chalupta, 1997). Distance pollen in pollination successes might be due to they have similar flowering characteristics. Moreover, insect pollinator works more effectively and is attractive in peak flowering and shiny season (Kang, 2000). Under flowering synchronization, reproductive success also could be restricted by prezygotic barriers (Larson et al., 2012) and assortative mating (mate choice) factors (Maroja et al., 2009). These barriers might be controlled by some genes within region and strongly prevent the reproductive success (Larson, White, Ross & Harrison, 2014). These gene barriers might determine the concept of combining ability i.e. general combining ability and specific combining ability of plant species.

IV. CONCLUSION

The study revealed that mating system within the SSO was near panmixia equilibrium. Paternal analyses showed a maternal tree of *A. mangium* tended to be pollinated by more than one paternal tree. Such maternal trees might be used to better design the clonal seed orchard in the future tree improvement strategy of this species. The mating system also showed that two good performance offsprings were fathered by one paternal tree; it showed that effect of inbreeding depression in *A. mangium* could be ignored. Flowering synchronization among the identified parent trees should be assessed in a future study, to maximize seeds production from the orchard.

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EARLY GROWTH AND STAND VOLUME PRODUCTIVITY OF SELECTED CLONES OF *Eucalyptus pellita*

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EARLY GROWTH AND STAND VOLUME PRODUCTIVITY OF SELECTED CLONES OF *Eucalyptus pellita*. Using current technologies, several forest plantation companies in Indonesia are pursuing clonal forestry program with *E. pellita* to increase plantation productivity using selected clones. This paper evaluates the early growth and stand volume productivity of selected clones of *E. pellita* as part of a breeding program for pulpwood. Two clonal trials of *E. pellita* were established in Central Java with two different plot configurations: single tree-plot and multiple tree-plot. Trial evaluation was done at two years age involving tree height, diameter, stem volume and stand volume. Result show that among the clones there were significant differences for all traits assessed. All of the tested clones exceeded the control seedling of F-1 generation by 9-50% for height, 10-36% for diameter and 22-137% for stem volume, respectively. Clonal repeatability ranged from 0.7-0.9, with corresponding individual ramet repeatability ranged from 0.2-0.4. Overall stand volume productivity at given age reached 15 m^3/ha.

Keywords: Clonal forestry, clone, *Eucalyptus pellita*, growth, stand volume

PERTUMBUHAN AWAL DAN PRODUKTIVITAS VOLUME TEGAKAN KLON Eucalyptus pellita *TERPILIH. Dengan menggunakan teknologi terkini, beberapa perusahaan HTI di Indonesia mengedepankan program perhutanan klon* E.pellita *untuk meningkatkan produktivitas tanaman melalui penggunaan klon-klon terpilih. Tulisan ini mengevaluasi pertumbuhan awal dan produktivitas volume tegakan klon* E. pellita *terpilih sebagai bagian dari program pemuliaan kayu pulp. Dua uji klon* E. pellita *telah dibangun di Jawa Tengah dengan konfigurasi plot yang berbeda: plot dengan pohon tunggal dan plot dengan banyak pohon. Evaluasi dilakukan pada umur dua tahun pada sifat tinggi pohon, diameter, volume batang dan volume tegakan. Penelitian menunjukkan adanya perbedaan yang signifikan diantara klon yang diuji pada seluruh sifat yang diamati. Seluruh klon yang diuji lebih baik dibanding kontrol yang berupa tanaman yang berasal dari benih F-1, dengan peningkatan 9-50% pada tinggi, 10-36% pada diameter dan 22-137% pada volume batang. Repeatabilitas klonal berkisar 0,7-0,9 dengan repeatabilitas ramet individual berkisar 0,2-0,4. Secara keseluruhan produktivitas volume tegakan pada umur tersebut mencapai 15 m^3/ha.*

Kata kunci: Perhutanan klonal, klon, Eucalyptus pellita*, pertumbuhan, volume tegakan*

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I. INTRODUCTION

Eucalyptus pellita F. Muell. is a fast-growing tree species that are widely developed for plantation forest in Indonesia. About 83.000 hectares of *E. pellita* plantations have been established to supply raw material for the pulp and paper industries (Hardiyanto, 2010b). The Ministry of Forestry has set a target of 5 million hectares for industrial forest plantation development (Rufi'ie, Prihatini, Subarudi, & Fatmawati, 2005).

The conventional breeding (open pollination) of E. pellita was not able to provide optimum results to increase the productivity because of high variations in stand growth (Sachs, Lee, Ripperda, & Woodward, 1988). The advanced breeding through clonal development can further improve the productivity of *E. pellita* by using the best clones, the plantation productivity (yield) can increase and it can produce a relatively uniform stand growth. Some countries have successfully developed and proven that Eucalyptus clones produced genetically good plantations with relatively uniform stands which are more economical compared to seedlings (Libby & Ahuja, 1992).

In 2011, in order to improve the productivity of *E. pellita* through advanced breeding strategy, the Center for Forest Biotechnology and Tree Improvement, Yogyakarta has developed a clonal test in Wonogiri, Central Java. An evaluation of the trial was conducted with the main objective to determine growth and stand volume productivity at the age of 2 years.

II. MATERIAL AND METHOD

A. Clonal Propagation

Clones were collected from first generation of Seedling Seed Orchard (SSO F-1) in Wonogiri (Central Java), which was established in 1996. Clonal propagation was done by rejuvenating the 11 years old plus trees and propagated using cuttings of shoots (Kartikaningtyas & Yuliastuti, 2011). There were 7 clones to be tested that were selected based on the rooting ability. In addition, there were 2 additional clones that were collected from the 11 years old bulkseed plantation. The information of all clones tested in the trials is presented in Table 1.

B. Trial Design and Measurement

The trials were established in 2011 at Wonogiri Central Java by using single tree plot and multiple tree plot model (Sunarti, Setyaji, Nirsatmanto, & Kartikaningtyas, 2011). The single tree plot model was used to obtain information on genetic parameter values, while the multiple tree plot was arranged to assess the productivity. The trials were built in a completely randomized block design (RCBD), 9 clones, spacing 3 m x 2 m and 16 blocks of replication. For the multiple tree plot model, 16 ramets (4 x 4) was used for each clone. Seedlings were taken from SSO F-1 *E. pellita* Wonogiri, Central Java and were also planted in the trials as control. Measurement was conducted 2 years after planting regarding height, diameter at breast height (dbh) and stem volume. The

Table 1. Information of the tested clones.

Clone	Seedlot	Origin Provenance	Plantation
1	495	18199-CG 1903 Serisa Village WP, PNG	SSO
2	-	-	Bulkseed
3	519	18200-BVG 2214 Keru To Nata WP,PNG	SSO
4	498	18199-CG 1090 Serisa Village WP, PNG	SSO
5	430	18197-CG 1882 South of Kiriwo, PNG	SSO
7	-	-	Bulkseed
8	518	18200-BVG 2213 Keru To Nata WP,PNG	SSO
9	502	18199-CG1912 Serisa Village WP, PNG	SSO
14	464	18197-BVG 2171 North of Kiriwo, PNG	SSO

Table 2. Site description of *E. pellita* clonal test

Item	Information
Administration	Wonogiri, Central Java
Geographic position	7º80' S and 110º93'E
Climate (Schmidt-Fergusson)	Type D
Rain fall (mm/year)	1878
Temperature (min – max)	21 - 32°C
Soil Order	Vertisol
Elevation (m asl)	141
Slope (%)	10

Source: Sunarti, Setyaji, Nirsatmanto, and Kartikaningtyas (2011)

traits were recorded in quantitative scale: meter (m), centimeter (cm) and meter cubic (m^3) for height, diameter and stem volume respectively. Detailed information of the two locations is shown in Table 2.

C. Data Analysis

1. Analysis of variance

Analysis of variance was done of individual data with a linear model according to Hardiyanto (2010 b) as follows (Equation 1):

$$Y_{ij} = \mu + R_i + C_j + E_{ij} \quad (1)$$

where :

Y_{ij} : individual observation of the j^{-th} clone in the i^{-th} replication

μ : mean of population

R_i : an effect of the i^{-th} replication

C_j : an effect of the j^{-th} clone

E_{ij} : error associated with Y_{ij}

2. Repeatability values

The estimation of repeatability was calculated for clone (heritability of mean clone) and ramet (individual heritability) using formula of Gonçales et al., (2006) as shown in Equations 2 and 3 as follows:

Clone Repeatability :

$$H_c^2 = \frac{\sigma_c^2}{\sigma_c^2 + (\sigma_c^2 \,/\, b)} \quad (2)$$

Ramet Repeatability :

$$h_r^2 = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2} \quad (3)$$

where :

H^2c : clone repeatability

h^2r : ramet repeatability

σ^2c : clone variance component

σ^2e : error variance component

b : replication

3. Ranking of clones and productivity

The clones were ranked using DMRT (Duncan Multiple Range Test) to find the best clone. The productivity of clone at each trait was calculated using the formula according to Sunarti (2013) as follows:

$$\text{Productivity} = \frac{\text{clone - control}}{\text{control}} \times 100\% \quad (4)$$

III. RESULT AND DISCUSSION

A. Variance Components and Clone Repeatability

The result of analysis of variance for each test as well as across test are shown in Table 3. The differences among clones on all traits in the site were highly significant. The differences reflected the influence of genetic factors on the growth indicating that selection of clones for increasing the productivity of *E. pellita* stands is justified. Table 3 also shows that the variance components of clones were 0.70932, 0.16850, 5.72419E-6, for height, diameter and stem volume, respectively. Clone and ramet repeatability for height were 0.89 and 0.41, respectivelly. While repeatability for diameter were 0.68 for clone mean and 0.16 for ramet. According to Falconer (1989) the values were categorized as moderate to high.

Table 3. Estimation of variance component and family heritability by single and across test

	Traits		
	Height (m)	Diameter (cm)	Stem Volume (m^3)
Mean	7.05	5.86	0.0109
Clone variance component (σ^2_c)	0.70932**	0.16850**	5.72419E-6**
Clone repeatibility (H^2_c)	0.89	0.68	-
Ramet repeatibility (h^2_r)	0.41	0.16	-
Control	5.64	4.66	0.0063

Remarks: ** : significant at 1%

Table 4. Rank and gain of clones in comparison with control

Rank	Traits								
	Height (m)			Diameter (cm)			Stem Volume (m^3)		
	clone	mean	gain(%)	clone	mean	gain (%)	clone	mean	gain (%)
1	1	8.49	50.42	2	6.33	35.94	1	0.01	136.51
2	2	8.23	45.85	14	6.29	34.96	2	0.01	122.22
3	3	7.70	36.59	1	6.28	34.69	14	0.01	103.17
4	14	7.39	31.03	8	6.04	29.59	3	0.01	76.19
5	4	6.86	21.59	4	6.04	29.55	4	0.01	74.60
6	7	6.60	17.09	3	5.74	23.30	8	0.01	57.14
7	9	6.31	11.89	5	5.39	15.67	7	0.01	41.27
8	5	6.15	9.11	7	5.21	11.81	5	0.01	25.40
9	8	6.13	8.66	9	5.13	10.13	9	0.01	22.22
Control		5.64			4.66			0.01	

Studies on clonal test of 2 years old *E. grandis* after planting in Portugal showed that clones repeatability was almost the same or about 0.87 to 0.91 (Borralho, Almeida, & Cotterill, 1992). The study in Vietnam of *E. camaldulensis* clone at 3 years age also showed the value of about 0.72 to 0.88 (Kien, 2009). The high repeatability estimation value indicates the high potential of clones to be vegetatively propagated.

B. Rank and Productivity

The clone rank and gain in comparison with control in all traits are shown in Table 4. The same table shows that all of the clones tested proved superior to the control of seedling of F-1 generation. The clones superiority to control seedling *E. pellita* F-1 were 9 - 50% for height, 10 – 36% for diameter and 22 – 137% for stem volume, respectively.

The results of other studies also indicated that clones superiority to seedling was also found in hybrid clones of *E. grandis* x *E. camadulensis* in Africa (Quaile, 1988), hybrid of *E. pellita* x *E. urophylla* in Zimbabwe (Gwaze, Bridgwater, & Lowe, 2000) and the hybrid of *E. urophylla* x *E. grandis* in Kalimantan (Hardiyanto & Tridasa, 2000).

In this study, the best three clones for height growth were number 1, 2 and 3 with the superiority ranging from 37 - 50% compared with the control (Table 4) and ranging from 9 - 20 % compared with the average of total clones (Table 5). While for diameter, the best three clones were number 1, 2 and 14 with the superiority ranging from 35 - 36% compared with the control (Table 4) and ranging from 8 - 9 % above the average of the total clones (Table 5).

In case of stem volume, the best three clones were number 1, 2 and 14 with the superiority ranging from 103 - 137% compared with the control (Table 4) and ranging from 17 - 36 %

Table 5. Gain (compared with clones average) and estimation of stand volume of the best three clones

Rank	Traits									
	Height(m)			Diameter (cm)			Stem Volume(m^3)			Stand Volume (m^3/ha)
	clone	mean	gain(%)	clone	mean	gain (%)	clone	mean	gain (%)	
1	1	8.49	19.57	2	6.33	8.69	1	0.02	36.49	16.7
2	2	8.23	15.94	14	6.29	7.90	2	0.01	28.21	15.6
3	3	7.70	8.57	1	6.26	7.69	14	0.01	17.11	14.4
4	14	7.39	--	8	6.04	--	3	0.01	--	--
5	4	6.86	--	4	6.04	--	4	0.01	--	--
6	7	6.60	--	3	5.74	--	8	0.01	--	--
7	9	6.31	--	5	5.39	--	7	0.01	--	--
8	5	6.15	--	7	5.21	--	5	0.01	--	--
9	8	6.13	--	9	5.13	--	9	0.01	--	--
Clone average		7.05			5.87			0.01		

compared with the average of total clones (Table 5). The clones number 1 and 14 were the clones which originated from provenance of Papua New Guinea i.e: *Serisa* Village and North of Kiriwo. While clone number 2 was a clone collected from selected plus trees in bulkseed plantation with unknown origin. Table 5 shows that the projection of stand volume from the best selected three clones were 14.4, 15.6 and 16.7 m^3/ha, for clones 14, 2 and 1, respectively with the average of all three clones of 15 m^3/ha. These results indicate considerable opportunities in implementing the clonal forestry for increased productivity of *E. pellita* stands.

The use of clonal forests of eucalypts is currently widespread in Brazil that use Eucalyptus for industrial purposes.The total area planted with clones is over 1 million ha. Besides the expectation of higher productivity as expressed in the final product per hectare, the plantations also provide the incorporation of higher quality wood in the various end uses for which the breeding programs are being directed (de Assis, Rezende, & Aguiar, 2012). With the limited concessions area available in Indonesia, it is very important to increase yield of plantations to be able to supply adequate raw material to the industry. Significant improvement of wood production can be obtained by applying best silvicultural practices and through genetic improvement programs particularly through clonal forestry project such as with *E. pellita*.

IV. CONCLUSION

Although the evaluation was done using the data collected from relatively young plants, these results indicated considerable opportunities in implementing the clone selection for increased stand productivity of *E. pellita*. This clone test evaluation should be continued to determine the variation in growth and other properties.

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IMPACTS, PATTERNS, INFLUENCING FACTORS AND POLICIES OF FUELWOOD EXTRACTION IN WAY KAMBAS NATIONAL PARK, INDONESIA

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IMPACTS, PATTERNS, INFLUENCING FACTORS, AND POLICIES OF FUELWOOD EXTRACTION IN WAY KAMBAS NATIONAL PARK, INDONESIA. Uncontrolled fuelwood extraction from conservation forest of Way Kambas National Park (WKNP) could threaten the existing forest. This paper studies the way to tackle the forest degradation in WKNP, with less negative impacts to the local people. Study was conducted by analysing existing data and maps of WKNP in terms of forest degradation, forest inventories, current policies, survey on how fuelwood is extracted, observation on fuelwood gatherers, fuelwood demand, and identification of further policy options. Results show that the most significant factors influencing the fuelwood extraction activity in WKNP are land ownership, followed by the distance to forest area, income level, the number of household members and age of household head. In the field, the fuelwood utilization is allowed by WKNP Authority, although it is formally forbidden.It was stated that fuelwood extraction in the area should be less than 2.89 ton/ha/year to maintain its sustainability, based on the mean WNKP forest tree annual increment. The fact shows that fuelwood extraction in WKNP reduces of forest biomass stock (1.06 tons/ha/year) and decreases species diversity index (from 3.05 to 2.45), species evenness index (from 1.06 to 0.91) and old-young tree ratio (from 1.29 to 1). Ecosystem quality reduction is mainly caused by destructive techniques in extracting fuelwood such as slashing, scratching cambium, and cutting trees. Therefore, recommended policy includes legalizing fuelwood extraction with restrictions, providing alternative fuelwood and other biomass energy resources outside WKNP, conducting preventive (establishing checkpoints and increasing patrols) and pre-emptive (educating and campaigning) efforts, collaborating with other stakeholders, and empowering local economy.

Keywords: Fuelwood, national park, forest extraction, deforestation, rural energy

DAMPAK, POLA, FAKTOR YANG BERPENGARUH, DAN KEBIJAKAN PEMANFAATAN KAYU BAKAR DI TAMAN NASIONAL WAY KAMBAS. Pamanfaatan kayu bakar dari hutan konservasi, seperti Taman Nasional Way Kambas (TNWK), dapat mengancam keberadaan hutan apabila dilakukan tanpa kontrol yang baik. Tulisan ini mempelajari cara mengatasi degradasi hutan di TNWK, dengan dampak negatif minimal bagi masyarakat lokal. Metode penelitian meliputi analisis data dan peta TNWK terkait dengan degradasi hutan, inventarisasi, analisis kebijakan saat ini, survei pengambilan kayu bakar, pengamatan terhadap pengumpul kayu bakar, survei permintaan kayu bakar, dan identifikasi pilihan kebijakan selanjutnya. Hasil penelitian menunjukkan bahwa faktor yang paling signifikan mempengaruhi aktivitas ekstraksi kayu bakar di TNWK adalah kepemilikan tanah, diikuti oleh jarak ke kawasan hutan, tingkat pendapatan, jumlah anggota rumah tangga, dan usia kepala rumah tangga. Aktivitas pemungutan kayu bakar ini terjadi di kawasan TNWK, meskipun dilarang oleh peraturan formal di tingkat nasional, sehingga prinsip pengambilan kayu bakar secara berkelanjutan harus kurang dari 2,89 ton/ha/tahun (pertumbuhan rata-rata tahunan hutan TNWK dalam kondisi normal). Fakta dilapangan menunjukan bahwa pengambilan kayu bakar di TNWK menurunkan stok biomasa hutan (1,06 ton/ha/tahun) dan menurunkan indeks keanekaragaman jenis (dari 3,05 menjadi 2,45), indeks kemerataan jenis (dari 1,06 menjadi 0,91), dan rasio pohon-permudaan (dari 1,29 menjadi 1). Penurunan kualitas ekosistem disebabkan karena penggunaan teknik yang merusak seperti meranting, menderes, dan menebang. Oleh karena itu,

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beberapa pilihan kebijakan yang direkomendasikan adalah melegalisasi pengambilan kayu bakar dengan batasan-batasan tertentu, menyediakan sumber alternatif kayu bakar dan energi biomassa lain di luar kawasan TNWK, melakukan upaya pencegahan (mendirikan pos-pos pemeriksaan dan meningkatkan patroli) dan pre-emptive (mendidik dan berkampanye), bekerja sama dengan pemangku kepentingan lainnya, dan memberdayakan ekonomi lokal.

Kata kunci: Kayu bakar, taman nasional, ekstraksi hutan, deforestasi, energi pedesaan

I. INTRODUCTION

Fuelwood has been used since the ancient centuries, and until now it is still an important source of energy at many places. Global demand for fuelwood might even increase in the future based on the fact that most European Union countries increase their biomass consumption as a renewable source of energy for power and heat plants (Verhoest & Ryckmans, 2012). In Asia, the number of people rely on fuelwood is about 1.711 billion people and is predicted to increase to 1.733 billion in 2030 (Organisation for Economic Co-operation and Development, 2002). Accordingly, about 1.5016 billion cubic meters per year of fuelwood are needed to fill the need of fuel energy globally. The main fuelwood used countries are located in Africa, South America, South Asia, East Asia, and Southeast Asia (Broadhead, Bahdon, & Whiteman, 2001). In South Korea, the use of biomass as a portion of renewable energy is predicted to increase from 6% to more than 30% by 2030 (Chanal, 2012). In Indonesia, around 47.71% or about 26.2 million household rely on fuelwood and generally live in rural areas (Department of Forestry, 2005). Although recently these household have begun to use Liquid Petroleum Gas (LPG) and electricity, fuelwood demand remains high, particularly in the areas close to forest with low accessibility for modern energy sources (Arnold, Kohlin, Persson, & Shepherd, 2003).

Supply of fuelwood in Indonesia comes from non-forest area (65%), from production forest area (6%), and about 29% from unknown sources (Arnold et al., 2003). Conservation forest areas such as national parks that are adjacent to villages then become also source of fuelwood for the local people although it is illegal. The 29% supply of fuelwood mentioned by Arnold et al. (2003), might then partly comes from conservation forest areas. Way Kambas National Park (WKNP) in Lampung Province which is surrounded by 37 villages with around 34,000 household (WKNP Authority, 2011) has become the source of fuelwood for the local people.

Without a good control, fuelwood extraction from conservation forest can threaten the forest´s existence. Simon (1999) stated that in areas dominated by community uses, forest destruction usually begins with fuelwood extraction, followed by illegal logging and finally by forest occupation. As one of the influencing factors for the destruction of conservation forests, fuelwood extraction should then be controlled. The aim of this research is to find appropriate solutions to avoid further forest degradation in WKNP, without negative impacts on the well-being of the local people who use the fuelwood, including recommendations for an appropriate policy on fuelwood extraction, based on the understanding of the impacts, patterns, influencing factors and the existing policies of fuelwood extraction in WKNP.

II. MATERIAL AND METHOD

A. Research Site Selection

The research was conducted at Way Kambas National Park in Lampung Province, Indonesia and its adjacent villages from April to August 2013. Data were collected using forest inventory method at three different locations of WKNP forest, namely: (1) forest area located more than 5 km from the border of *Labuhan Ratu* VI Village, (2) forest area that is directly bordered with *Labuhan Ratu* VI Village, and (3) forest area that bordered with *Rantau Jaya Udik* II Village. The first location was chosen because there was no villager activity in the area. The second location was chosen because *Labuhan Ratu* VI is located next to the office of WKNP and forest ranger, and the villagers are allowed to enter WKNP area for fuelwood gathering only under control of forest rangers. *Rantau Jaya Udik* II village is located far from WKNP office, so it was selected due to limited access of forest rangers to the area. Villagers from *Rantau Jaya Udik* II entered WKNP forest area not only for collecting fuelwood, but also for grazing animal, farming, logging, hunting, and fishing. Thus, it is presumed that the forest near this village is degraded due to various activities. Data were also collected using socio-economic survey at *Labuhan Ratu* VI Village which was selected due to its location that near WKNP and forest rangers offices.

B. Data Collection and Analysis

To understand the impacts of fuelwood extraction, forest inventories and data collection were conducted in three different conditions of WKNP forest (the forest area with no villager activity; the degraded forest area due to fuelwood extraction only; and the degraded area due to mixed activities). A pilot survey was conducted in each location to calculate required sample size. Three plots were selected randomly as preliminary samples. Figure 1 was an example of typical plots for forest inventory at the tropical woodlands (Verplanke & Zahabu, 2009):

$$n = \frac{CV^2 \times t^2}{E^2}$$

Where:

n = sample size

CV = coefficient of variation which was the measure of variability of tree cross-sectional area at breast height

t = expression of confidence that the true average was within the estimated range. For three plots this always had a value of 2.353

E = error that you were willing to accept in the final estimation

Number of sample size depended on the coefficient of variation of the three plots invented in the pilot survey in each location. There were six required plots in the first location, ten plots in the second location and 16 plots in the third location that were spread out evenly over the whole area in each forest location. The data were then used to measure the biomass in each forest location by using equation as below (Brown et al., 1989):

$$y = \exp\left[-3.1141 + 0.9719 \ln\left(D^2H\right)\right]$$

Where:

exp [...] means "raised to the power of [...]"

y = above-ground biomass in kg

H = height in m

D = diameter in m, at breast height (1.3 m)

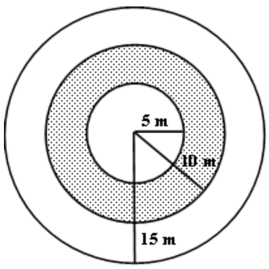

Figure 1. Sample plot of forest inventory

Remarks: Mixed activities are the activity of villagers that enter WKNP not only for extracting fuelwood, but also for grazing animal, farming, logging, hunting, and fishing.

- Within 5 m radius: inventory of saplings (young trees with DBH less than 10 cm)
- Within 10 m radius: inventory of poles (trees with DBH between 10 cm and 20 cm).
- Within 15 m radius: inventory of trees with DBH more than 20 cm

This equation was developed to estimate the weight of vegetation based on dimensional measurement (height and diameter). It was effectively applied in the area with annual rainfall from 1,500 to 4,000 mm (Brown et al., 1989) such as in WKNP forest.

In calculating the rate of forest biomass stock reduction and mean annual increments, some information based on interview with key informants were used as the base line. The information were: (1) the forest age in the three locations invented was approximately 30 years, because the existing forest was a secondary forest resulted from reforestation in 1980's where the original forest in these locations were completely destroyed by logging concession activity, forest occupation, and forest fire, (2) people surrounding the locations had invaded WKNP for fuelwood since approximately 8 years ago, because there was not enough fuelwood sources in the village and the forest resulted from the reforestation was now mature enough (approximately 22 years old) for fuelwood sources. Estimation of the mean annual increments and forest biomass stock reduction in this research was done as follows:

1) Mean annual increments = Current forest biomass stock/Forest age. (Mean annual increments calculation was only valid for forest in normal condition or no villager activity).
2) Forest biomass stock when fuelwood extraction start = Mean annual increment * Forest age when fuelwood extraction start
3) Forest biomass stock reduction = Forest biomass stock when fuelwood extraction start – Current forest biomass stock
4) Rate of forest biomass stock reduction = Forest biomass stock reduction / Time of fuelwood extraction

Observation and comparison of the data in the three locations were arranged by comparing the species number found (SN), the diversity index (Ludwig & Reynolds, 1988), the evenness index (Magurran, 1988), and the ratio between trees and saplings (OYR).

Survey on how fuelwood was extracted and the fuelwood demand was conducted to understand the patterns and the influencing factors of fuelwood extraction in WKNP forest. Samples were selected randomly (Black, 2008) and the sample size was calculated by using statistical equation (Yamane, 1967) as follows:

$$n = \frac{N}{\left(N.d^{2}\right) + 1}$$

Where:
n = sample size
N= population size
d = precision/critical value assigned 10% (0.1) for the 95% level of confidence

In the survey on fuelwood extraction, 80 respondents (fuelwood gatherers) were divided in two groups (32 professional and 48 subsistence gatherers). The division was conducted to understand the differences of fuelwood extraction pattern between the two groups. The population size of professional gatherer was 347 people and subsistence gatherer was 524 people. All respondents were interviewed by using questionnaires. Then, 15 respondents (six professional and nine subsistence gatherers) were chosen as key informants by purposive sampling and snowball sampling based on the criteria that each key informant must had enough knowledge, ability and willingness to help in answering the research question (Verschuren & Doorewaard, 2010). These key informants were lent GPS devices to record their tracks from their houses to WKNP forest area where they collected fuelwood. The data were then used to map the movement of fuelwood gatherers. Eighty women in the families were interviewed by using questionnaires to collect data on fuelwood demand. Housewives were chosen because mostly they were the direct users of fuelwood and knew exactly the fuelwood consumption for their families. Sampling method was conducted by systematic random sampling. All data gathered from this survey were analysed by variance analysis and multiple linear regression analysis.

Current policies on fuelwood extraction

Table 1. Biomass measurement in the three different forest conditions of WKNP Forest

Label	No villager activity	Fuelwood extraction	Mixed Activities
Number of sample plots	6	10	16
Current forest biomass stock (tons/ha)	86.74	55.11	10.85
Forest age (year)	30	30	30
Mean annual increments (tons/ha/year)	2.89	-	-
Forest age when fuelwood extraction start (year)	-	22	22
Forest biomass stock when fuelwood extraction start (tons/ha)	-	63.58	63.58
Time of fuelwood extraction (year)	-	8	8
Forest biomass stock reduction in 8 years (tons/ha)	-	8.47	52.73
Rate of forest stock reduction (tons/ha/year)	-	1.06	6.59

in WKNP were reviewed and analysed. Information and data were collected by interviewing 10 key informants representing top management of WKNP (1 person), forest rangers (2 people), WKNP staff (2 people), local people (3 people), and village leaders (2 people). Purposive sampling was chosen to ensure that every key informant had rich information to answer the research question (Verschuren & Doorewaard, 2010). Then, qualitative method of data analysis was chosen in this study. The analysis was started during the data collection and/or after a certain period of the data collection where during the interview, the researcher started to conduct the data analysis of the responses obtained from the interview. Cross check with the triangulation method was also done to avoid any bias in the research results by analysing the data from multiple sources such as interviews, observations and documents (Cresswell, 1994).

III. RESULT AND DISCUSSION

A. Fuelwood Extraction Impacts

Table 1 reveals that fuelwood extraction activity led to the reduction of forest biomass stock. In the location with only fuelwood extraction activity, forest biomass stock declines from 63.58 tons/ha to 55.11 tons/ha in 8 years or the rate of forest biomass stock reduction in this location is about 1.06 tons/ha per year. The reduction of forest biomass stock is much higher in the location with mixed activities. The forest lost its stock by 52.73 tons/ha in 8 years period or 6.59 tons/ha per year. Complete information about the forest biomass stock calculation can be found in Appendix 1.

The natural forests of the three research locations have the same vegetation characteristics before they are destroyed by logging concessions. This is because the three locations are in the same forest region. Furthermore, reforestation programs in the locations grow new vegetation that are similar to natural vegetation.

Based on Table 2, in the location with no villager activity, old trees have high species diversity (3.05), followed by young trees with medium diversity (2.40). Old trees also have higher evenness index (1.06) than young trees (0.91) with old-young tree ratio of 1.29. This indicates that the forest is in recovery phase from secondary forest to primary forest. Meanwhile, surrounding *Labuhan Ratu* VI Village where only fuelwood extraction occurred, young trees have a slightly higher species diversity index (2.50) than old trees (2.45) although both still have medium diversity. Furthermore, the evenness index of the two vegetation levels in this location is nearly the same with old-young tree ratio of 1. This also indicates that the forest still in the improvement stage to primary forest.

Table 1. Diversity index, evenness index and old-young tree ratio in the three different forest conditions of WKNP

Vegetation Level	No villager activity				Fuelwood Extraction Only				Mixed Activities			
	SN	H'	E	OYR	SN	H'	E	OYR	SN	H'	E	OYR
Old > 0.2 m DBH	18	3.05	1.06	1.29	15	2.45	0.91	1	2	0.23	0.33	0.22
Young < 0.2 m DBH	14	2.40	0.91		15	2.50	0.92		9	1.92	0.87	

Remarks: SN = Species number found; H' = Diversity Index; E = Evenness Index; OYR = Old-Young Tree Ratio

Opposing the location with no villager activity, in mixed activities forest, old trees have lower diversity index (0.23) and evenness index (0.33) than young trees with 1.92 of diversity index and 0.87 of evenness index. Moreover, old-young tree ratio in this forest is 0.22. This data show that fuelwood extraction only actually caused less forest degradation compared to mixed activities. This means that other activities such as grazing animal, farming, logging, hunting and fishing simultaneously caused more damage to the forest.

Table 2 also reveals that there are changes in forest conditions as a consequence of fuelwood extraction. In the old tree level, there is a significant decline in diversity from 3.05 in normal condition to 2.45 with fuelwood extraction only. Then, the index falls significantly to 0.23 in mixed activities. Furthermore, there is also a downward trend of evenness index from 1.06 in normal condition to 0.91 in fuelwood extraction only and it falls to 0.33 in mixed activities. However, for younger vegetation, there are upward trends in both diversity and evenness index from normal condition to fuelwood extraction only. These happened because more sunlight in more open forest with fuelwood extraction stimulates the invasion of new species and the growth of seedlings, so this increases the diversity and evenness index. Meanwhile, old-young tree ratio decreases from 1.29 in normal condition to 1 in the location with fuelwood extraction only, and it declines to 0.22 in mixed activities.

In the long term, these changes will transform the structure of forest ecosystem and the vegetation including wildlife condition inside such as birds and insects. These findings are congruent with several previous studies stating that fuelwood extraction can generate forest degradation (Skutsch & Ghilardi, 2008), slow plant productivity and forest regeneration (Sankaran & McNaughton, 2005). This will lead to substantial changes in forest ecosystem as a result of the changes in vegetation structure, diversity, and composition (Mehta, Sullivan, Walter, Krishnaswamy, & DeGloria, 2008), that could end in the reduction of biodiversity, particularly birds, reptiles and insects (Brown et al., 2010).

B. Fuelwood Extraction Patterns

The survey shows that most fuelwood gatherers, both professional and subsistence, collect dry and fallen twigs and branches. However, some of both professional and subsistence gatherers still conduct destructive techniques such as slashing green twigs and branches, scratching cambium and cutting the trees in extracting fuelwood. Due to this destructive fuelwood extractions, forest growth is disturbed significantly, because young trees cannot grow optimally and/or die. Thus, these practices trigger the reduction in forest biomass stock and mean annual increment of the forest. The changes of vegetation structure caused

Table 3. Biomass measurement in the three different forest conditions of WKNP

Label	Subsistence Gatherers	Professional Gatherers	Professional-Subsistence Ratio
The number of trip per year	195 trips/year	412 trips/year	2.11
The amount of fuelwood gathered per trip	30 kg	50 kg	1.67
The amount of fuelwood gathered per year	5,840 kg/year	20,580 kg/year	3.52

by these practices then also led to the changes in species diversity, species evenness and old-young tree ratio.

Table 3 shows that one professional gatherer could extract fuelwood about 3.52 times more than one subsistence gatherer in a year. Professional gatherers can also carry 1.67 more fuelwood in each trip compared to their counterpart, subsistence gatherers. One interesting fact in this table is that on average, a subsistence gatherer goes to WKNP forest around 195 trips per year or every 1-2 days. However, a professional gatherer could enter WKNP forest for fuelwood up to 412 trips per year. Since in a year is only 365 days, this indicates that a professional gatherer usually enter WKNP forest more than one time in a day. Most professional gatherers do not enter WKNP forest every day but irregularly. This means that professional gatherers usually decide one 'fuelwood gathering day' and they spend the whole day to extract fuelwood in WKNP forest. In a day, they could enter WKNP forest up to five times. This pattern is different from that of subsistence gatherers who usually spend only 1-2 hours in the forest every 1-2 days, usually after working on their farm land. Furthermore, motorcycle usage in transporting fuelwood is more often among professional gatherers compared to the subsistence gatherers. Considering these findings, professional gatherers tend to give more negative impacts than subsistence gatherers.

Moreover, by analysing the movement of the two gatherer groups, there is a tendency that WKNP area for fuelwood extraction in *Labuhan Ratu* VI Village widens to the Southeast, avoiding the WKNP Offices in the North. The areas where the professional and subsistence gatherers extract the fuelwood in WKNP are different. Most subsistence gatherers enter WKNP forest from 0 to 1 km. Meanwhile, the professional gatherers usually cross the WKNP border until 2 km depth. This is because professional gatherers need more fuelwood, so they have to go deeper than subsistence gatherers. Considering this fact, fuelwood extraction activity in this village should be anticipated by WKNP Authority as the starting point of the involvement of forest community in destructing conservation forest. Although it is not occurred yet in *Labuhan Ratu* VI, but it is possible when the location of fuelwood extraction is uncontrollable and far enough from the offices, people will start to do other illegal activities such as logging, grazing cattle, hunting, fishing and occupying forest.

C. Influencing Factors for Fuelwood Demand

Survey result shows that there are villagers in *Labuhan Ratu* VI Village who extracted fuelwood from WKNP forest for commercial purposes, although most villagers use fuelwood for subsistence purposes. This should be anticipated by WKNP Authority since the need of fuelwood for commercial purposes will increase in the future following the growth of population and small scale industry surrounding WKNP. As stated by Arnold et al. (2003), population growth and economic growth (Mathews, 2009) in rural areas will increase the need and the consumption of fuelwood.

Spatial pattern analysis shows that the catchment area of WKNP forest is about two kilometer from WKNP border. People who live more than two kilometer from the WKNP border or outside the catchment area, usually looking for the closer sources of fuelwood such as plantations. From the map analysis of *Labuhan Ratu* VI settlement, it can be estimated that about a half of the population in the village live near the WKNP, so that they depend on WKNP forest to fulfil their fuelwood needs. Number of household in *Labuhan Ratu* VI Village is 798 household (Lampung Timur's BoS, 2010), so that can be assumed 399 families in the village looked for fuelwood at the WKNP forest area.

Result of survey shows that the average fuelwood demand of villagers surrounding WNKP is about 487 kg/household/month or about 5,840 kg/household/year. The fuelwood needs are fulfilled mainly from WKNP forest and in small amount (±10%) from backyards and gardens. So, it can be calculated that the total demand of fuelwood from WKNP forest in Labuhan Ratu VI is about 2,097.14 tons/year. If the mean annual increment of WKNP forest is 2.89 ton/ha per year, it is estimated that the needs of WKNP forest as fuelwood resources in *Labuhan Ratu* VI is around 725.66 ha.

The calculation above does not include the population growth in *Labuhan Ratu* VI which is around 8.44% per year in average from 2005-2010 (Lampung Timur's BoS, 2010) that will increase the fuelwood demand significantly in the future. The high number of population in *Labuhan Ratu* IV is not only caused by birth rate but also by huge immigration of people from other areas. This means that the village is in transition or change from less to more developing village. In recent years many people especially from Java Island migrated to *Labuhan Ratu* VI and other neighbouring villages seeking for farm land and/or working as labours at new established plantation companies (cassava and fruits) in the area.

The research result (Table 4) shows that land ownership is the most significant factor in influencing fuelwood demand. Villagers with sufficient land tend to collect fuelwood from their own land, but people with limited land have less fuelwood sources, so they have to go to forest to find fuelwood. This means that the need of WKNP area for fuelwood sources is unavoidable. Furthermore, other influencing factors for fuelwood demand are income level and the distance to forest area. Villagers with higher income have stronger purchasing power to pay modern energy sources such as gas and electricity. However, villagers with very low income only depend on free energy sources such as fuelwood. Villagers living very close to forest can easily go to forest to collect fuelwood anytime, but other villagers living far from forest tend to search fuelwood in closer sources such as backyards and gardens before deciding to go to forest.

This research also reveals that the number of household members is another influencing factor. This is because household with more member need more energy, so their demand for fuelwood is higher than smaller family. Last, this study states that age of household head can influence the fuelwood demand. The images of fuelwood as outmoded and impractical energy sources trigger young families to avoid fuelwood usage if they can afford modern energy sources such as gas and electricity.

D. Existing Policy and Its Effectiveness

In Forestry Act No. 41 of 1999, it is stated in article 50, paragraph 3 e, that everyone is forbidden to enter state owned forest and extract any forest product (including fuelwood) without right and licence. Anyone breaking this rule will be subjected to 10 years imprisonment or 5 billion rupiah fine (article 78, paragraph 4). However, the study shows that there is a contradiction between formal law at national level and the field implementation where fuelwood extraction is allowable because of humanitarian reason, limited capacity and lack of awareness on fuelwood extraction impacts. This condition is triggered by the exorbitant

Table 4. Statistical examination results of the factors influencing fuelwood demand

Variable	Average	Significance	Coefficient Correlation
Constant		0.001	5.29
Distance to WKNP forest (X1)	627 meter	0.001	-0.29
Income level (X2)	Rp 6,328,090/year	0.001	-0.28
Land ownership (X3)	3,590 meter^2/household	0.001	-0.39
Number of household members (X4)	4 people/household	0.006	0.05
Education level (X5)	3 (junior high school)	0.111	-0.02
Age the head of the household (X6)	43 years old	0.029	0.14

sanctions and lack of awareness of local people concerning the regulation and sanctions. However, allowing fuelwood extraction in WKNP forest could cause another problems. There is no clear regulations on how much fuelwood can be extracted, how often villagers can enter the park, which zone is allowable for fuelwood extraction, what extraction technique can be applied, for what purpose the extraction can be done. All these conditions cause the failure in maintaining sustainable extraction of fuelwood in WKNP.

IV. POLICY RECOMMENDATION

A. Legalizing Limited Fuelwood Extraction in WKNP Forest

This policy aims to create a formal regulation to allow local people extracting fuelwood from WKNP forest. By legalizing fuelwood extraction in limited amount and making it explicitly, it is expected that WKNP Authority can control fuelwood extraction from the forest with better rules and regulations, clear guidelines and procedures, and defining clearly the party that is responsible for the policy implementation. In implementing this policy, the greatest challenge will come from the existing formal regulation at national level (Government Regulation No. 28 of 2011) stated that a national park can be used as energy sources (water, geothermal and wind) and for traditional utilization or own consumption by local people in the form of non-timber forest resource extraction. From this statement, the legality of fuelwood extraction in WKNP is in an unclear area. This is because the regulation does not state the utilization of biomass energy source from a national park. Therefore, fuelwood is not included as a source of energy that is allowed to be extracted from a national park. Furthermore, the regulation also stated that non-timber forest resource can be taken from the national park for traditional extraction (subsistence purposes). If fuelwood is considered as a timber forest product, then fuelwood collected from national park is considered as illegal. However, if dry and fallen twigs and branches are considered as non-timber forest resources, fuelwood collection in the form of dry fallen twig collection technique in utilization zone of the national park is legal. A successful policy then depends on this interpretation.

Besides wisely interpreting and implementing the regulation, legalization of fuelwood extraction in WKNP can be done by revising the existing government regulation; although, this is beyond the capacity of WKNP Authority, which is only an implementing unit of the higher institution, the Ministry of Environment and Forestry. However, WKNP Authority can advise the higher institutions through official letters, reports, and meetings. This step is not easy and needs a time as it will involve a long and complicated procedure to change the existing regulation, but it is possible.

WKNP Authority should control carefully the implementation of this policy especially the distortions that may occur in the field. It is very possible that the fuelwood gatherers still extract fuelwood by destructive techniques such as slashing, scratching cambium and cutting the trees. Furthermore, the legalization of fuelwood extraction may also trigger other illegal actions such as forest occupation, illegal hunting and logging in WKNP forest. Therefore, if this policy is implemented, it needs to have clearer regulations in terms of procedures and sanctions. In the implementation, the extraction zone/forest area, the maximum amount and frequency to collect and the cutting technique, must be regulated and controlled.

This policy should be implemented at WKNP level as a model to learn how the regulation impacts, before it is adopted nationally in all national parks in Indonesia. In order to ensure that the implementation of this policy stays on track, below are some suggested restrictions or regulations that might be appropriate:

1) Fuelwood extraction can only be done in the Utilization Zone of WKNP and it is permitted in national regulation. Utilization zone is the only zone in the national park that can be used for non-conservation purposes but without serious impacts to the whole ecosystem of the forest. The WKNP is divided into zones based on scientific studies. To ensure that local community know about this zone, it is needed to inform the villagers regularly about the natural and artificial borders of the zone as well as the purposes of the zone.
2) Fuelwood gathering technique is only allowed by collecting dry twigs and branches already fallen on the forest floor. It is forbidden to slash, scratch and cut the trees for fuelwood since it will disturb the forest ecosystem significantly.
3) Fuelwood gathering in WKNP is only for subsistence purposes (own consumption) of the local people, not for commercial purposes.
4) The amount of fuelwood taken from the forest must be less than 2.89 ton/ha per year (the mean annual increment of WKNP forest in normal condition). In practice, people must be restricted to take fuelwood no more than 15 kg/day/household. This number is based on the result of the survey on fuelwood demand where the actual need of fuelwood is around 487 kg/month/household.

To run new policies above, some steps could be taken in the field by WKNP Authority:

1) Building checkpoints in strategic locations to check the amount of fuel-wood taken from the forest, especially in the main road used by villagers to access WKNP border.
2) Closing other roads and footpaths apart from the main roads with checkpoints.
3) Increasing forest ranger patrol along the border and inside the forest, especially to the direction of human invasion. This is to prevent fuel-wood gatherers go beyond the Utilization Zone and to do forbidden techniques in extracting fuel-wood.

In order to prevent offences, some fines should be prepared and well socialised to villagers. The fines should not be too high and unpayable by the villagers, but they have to be expensive enough to deliver deterrence. The fines should also consider the income level of the villagers and the degree of the offence. Based on the average income level of villagers, fines for different offences are proposed below:

1) Rp 1,000 ($0.13) per 1 kg exceeding the limit of fuel-wood extraction per day (17 kg).
2) Rp 1,000,000 ($130) for extracting fuel-wood outside Utilization Zones of WKNP forest.
3) Rp 10,000,000 ($1300) for extracting fuel-wood by slashing green branches and twigs.
4) Rp 20,000,000 ($2600) for extracting fuel-wood by scratching cambium and cutting the trees.

B. Providing Alternative Fuelwood and Other Biomass Energy Resources Outside WKNP

High demand for fuelwood is the drive of fuelwood extraction from WKNP. Introducing energy alternatives to fuelwood and/or creating other sources of fuelwood would reduce fuelwood extraction from national park area. These new resources must be closer and more accessible than WKNP forest, so that they will reduce the number of people going to WKNP forest for fuelwood. To realize these efforts, WKNP Authority can perform the following steps: (1) Optimizing the development of agroforestry systems in the villages especially in the farms, plantations, backyards, or other public lands that are allowed to plant fast-growing wood species such as mangium (*Acacia mangium*) and albizia (*Falcataria mollucana*) as the alternative sources of fuelwood. This action is possible because there is still available land/area at the villages around the WKNP; (2) Encouraging the villagers surrounding the WKNP to use the biomass energy sources such as rice husk, coconut shell and others through the process of socialization, counselling, education and training; (3) Providing enough area in the buffer zone of WKNP for fuelwood tree species plantation. Due to lack of budget and human resources of WKNP Authority, in the short term this policy may not be able to solve fuelwood extraction problem in WKNP, but in the medium and long terms, this kind of policy will synergize with other policies and contribute to the reduction of fuelwood extraction from WKNP forest.

C. Preventive and Pre-emptive Efforts

Preventive and pre-emptive efforts have slight differences. Preventive efforts focus on means of watching and controlling, while the pre-emptive effort is more focused on campaigning, raising awareness and educating activities. Both of these efforts have a common goal, i.e. to prevent and to reduce the amount of fuel-wood extraction which may affect WKNP forest negatively, especially extraction that uses scratching cambium and cutting techniques.

In the context of fuelwood extraction issues, there is no preventive and pre-emptive effort conducted by WKNP Authority nowadays. Therefore, one preventive action that should be conducted by WKNP Authority is building checkpoints in the strategic locations. Another preventive action is increasing forest ranger patrols along the borders of WKNP. These two preventive actions aim to reduce bad practices in extracting fuelwood. This policy is important since without this, the fuelwood gatherers will feel free to do anything in extracting fuelwood, including scratching cambium, cutting the trees and over extracting.

Furthermore, pre-emptive actions that can be carried out by WKNP Authority are educating and campaigning on the negative impacts of bad practices and over extraction of fuelwood. For example, fuelwood extraction by slashing, scratching cambium and cutting trees can trigger forest degradation, forest biomass stock reduction, and changes in species diversity, evenness, and old-young tree ratio where in the long term, these changes will transform the structure of forest ecosystem and the vegetation including wildlife condition inside such as birds and insects. The action should involve other stakeholders, especially NGOs and local government. Moreover, it is important to educate local people and to train cadres to support conservation measures amongst the villagers. To incorporate this policy into existing program at WKNP, the policy should be implemented together with (being the integral part of) preventive and pre-emptive actions aiming to reduce other illegal activities such as forest occupation, illegal hunting, logging, grazing cattle. Indeed, this will save the cost and resources in the implementation of this policy.

D. Collaboration with Other Stakeholders

WKNP Authority needs to collaborate with all stakeholders in order to produce synchronized and synergistic policies on the issues of fuelwood extraction in WKNP. This is because the issue is not only the responsibility of WKNP Authority, but also a complex problem associated with multiple stakeholders. Collaboration is absolutely necessary because there are many things must be done beyond the capacity of WKNP Authority such as:

1) Improving the distribution of commercial energy such as LPG and electricity to all villages surrounding WKNP in order to increase people's access to these energy sources. Key stakeholders include local government, Ministry of Energy, and corporates in the field of energy.
2) Increasing the production and distribution of more efficient fuelwood stoves in the villages surrounding WKNP. Key stakeholders incude local government, Ministry of Energy, Ministry of Industry and corporates in the field of energy and manufacture.
3) Improving transportation facilities to increase public access for other energy sources. Key stakeholders include local government, provincial government and corporates in the field of infrastructure.
4) Increasing villagers' income, to increase purchasing power of villagers to buy commercial energy sources. Key stakeholders included local government, provincial government, Ministry of Agriculture, Ministry of Industry, NGO and corporates in the field of finance, agriculture and manufacture.
5) Encouraging the use of agricultural waste as alternative biomass energy sources that can replace the role of fuelwood. Key stakeholders include local government, Ministry of Energy, Ministry of Agriculture, NGO, and corporates in the field of energy and agriculture.

Indeed, the means above are beyond the capacity of WKNP Authority. However, it is possible to run by good coordination with all stakeholders. WKNP Authority needs to encourage the realization of the above means.

E. Empowering Local Economy

One of the most influencing factors in the extraction of fuelwood is income level. This factor has significant negative correlation to the level of fuelwood extraction where the lower the income level, the higher the level of fuelwood extraction. Based on this, efforts to increase villager's income level through economic empowerment are needed. The idea of economic empowerment to reduce fuelwood extraction is in line with Johannesen (2006) who stated that economic empowerment for people surrounding national park through the creation of jobs and stimulation of farming productivity will contribute to save conservation forest. The increased income will reduce the rate of fuelwood extraction because villagers may be able to pay commercial energy sources such as LPG and electricity. Economic empowerment efforts around WKNP can be done in several ways: (1) Involving and employing villagers in the development and management projects of WKNP, particularly in the area of work that does not require highly educated workforces, for example as porters, securities, merchants, and parking attendants; (2) Giving aid and assistance to villagers in the form of capital, farm equipment and training for human resources and capacity building; (3) Coordinating and synchronizing the community empowerment programs of WKNP with other stakeholders' program that are also responsible for the welfare of WKNP people such as Provincial Government, Local Government, private sector and NGOs.

Running preventive and pre-emptive efforts should be immediately implemented to prevent further degradation at WKNP. However, all policy options above should be run together since one policy will support another policy. In other words, the effectiveness and social impacts of one policy depend on the success of other policies. Some of the policies above, such as preventive and pre-emptive efforts, and economic empowerment, should not be run exclusively to address fuelwood issue, but be run together as an integral part of policy for other major issue in WKNP such as forest occupation, and grazing cattle. Indeed, this is to save the cost and resources in implementing the policy. In the end, this will increase the effectiveness and reduce the negative social impacts of the whole policy implementation.

V. CONCLUSION

This research concludes that fuelwood extraction in WKNP are influenced by surrounding community land ownership, the distance to forest area, income level, the number of household members, and age of household head. Although fuelwood extraction is forbidden by formal law at national level, in the field this activity is allowable which creates the failure in maintaining sustainable fuelwood extraction. This is supported by the fact that fuelwood extraction in WKNP triggers forest degradation, the reduction of forest biomass stock and the changes of species diversity, species evenness, and old-young tree ratio due to destructive techniques used such as slashing, scratching cambium and cutting trees. Therefore, some recommended policy options are legalizing limited fuelwood extraction, providing alternative fuelwood and other biomass energy resources outside WKNP, running preventive and pre-emptive measures, collaboration with other stakeholders and empowering local economy.

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Appendix 1. Forest Biomass Stock (FBS) calculation in the three forest conditions

Condition	Natural with no villager activity					Degraded by fuelwood extraction activity only					Degraded by Mixed Activities				
Location	More than 5 km depth from WKNP border					Surrounding *Labuhan Ratu* VI Village					Surrounding *Rantaujaya Udik* II Village				
Plot	< 0.2 m DBH		> 0.2 cm DBH		FBS average per plot	< 0.2 m DBH		> 0.2 m DBH		FBS average per plot	< 0.2 m DBH		> 0.2 m DBH		FVS average per plot
	FBS/plot	FBS/ha	FBS/plot	FBS/ha		FBS/plot	FBS/ha	FBS/plot	FBS/ha		FBS/plot	FBS/ha	FBS/plot	FBS/ha	
	ton/ 0.01 ha	ton/ha	ton/ 0.04 ha	ton/ha	ton/ha	ton/ 0.01 ha	ton/ha	ton/ 0.04 ha	ton/ha	ton/ha	ton/ 0.01 ha	ton/ha	ton/ 0.04 ha	ton/ha	ton/ha
1	1.1166	111.66	3.6372	90.93	101.30	0.2931	29.31	2.6692	66.73	48.02	0.1353	13.53	0.2044	5.11	9.32
2	1.0799	107.99	1.7372	43.43	75.71	0.3468	34.68	2.9556	73.89	54.29	0.1585	15.85	0.3204	8.01	11.93
3	1.2331	123.31	2.6592	66.48	94.90	1.1652	116.52	0.706	17.65	67.09	0.1593	15.93	0.5004	12.51	14.22
4	1.1248	112.48	1.6148	40.37	76.43	0.5804	58.04	1.0328	25.82	41.93	0.0741	7.41	0.2084	5.21	6.31
5	1.0632	106.32	1.7776	44.44	75.38	0.8729	87.29	1.6472	41.18	64.24	0.1353	13.53	0.4556	11.39	12.46
6	1.2148	121.48	2.8784	71.96	96.72	0.9076	90.76	1.2432	31.08	60.92	0.1366	13.66	0.3616	9.04	11.35
7						0.7798	77.98	0.9464	23.66	50.82	0.1042	10.42	0.5312	13.28	11.85
8						0.9121	91.21	0.8488	21.22	56.22	0.1043	10.43	0.3484	8.71	9.57
9						0.7693	76.93	1.5672	39.18	58.06	0.0986	9.86	0.6792	16.98	13.42
10						0.4432	44.32	2.1932	54.83	49.58	0.0441	4.41	0.3292	8.23	6.32
11											0.0743	7.43	0.2076	5.19	6.31
12											0.0352	3.52	0.3024	7.56	5.54
13											0.1578	15.78	0.5152	12.88	14.33
14											0.1086	10.86	0.8368	20.92	15.89
15											0.1758	17.58	0.376	9.4	13.49
16											0.0975	9.75	0.518	12.95	11.35
FBS average/ per location	86.74					55.11					10.85				

Reamarks : FBS = Forest Biomass Stock; DBH = Diameter at Breast Height

A COMPATIBLE ESTIMATION MODEL OF STEM VOLUME AND TAPER FOR *Acacia mangium* Willd. PLANTATIONS

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A COMPATIBLE ESTIMATION MODEL OF STEM VOLUME AND TAPER FOR *Acacia mangium* Willd. PLANTATIONS. This study describes the establishment of a compatible volume estimation model for *Acacia mangium* Willd on the basis of 279 felled sample trees collected from the *A. mangium* plantation stands in South Sumatra, Indonesia. The model comprises of a total volume model and a stem taper model, which is compatible in the sense of the total volume obtained by integration of the taper model being equal to that computed by the total volume model. Several well-known total volume functions were evaluated including constant form factor, combined variable, generalized combine variable, logarithmic, generalized logarithmic and Honer transformed variables. A logarithmic model was determined to be the best and was then used as the basis for deriving the taper model. Appropriate statistical procedures were used in model fitting to account for the problems of heteroscedasticity and autocorrelation that are associated with the construction of volume and taper functions. The simultaneous fitting method of the Seemingly Unrelated Regression (SUR) improved the parameter estimates and goodness-of-fit statistics while ensuring numeric consistency among the component models and reducing the total squared error obtained by an independent fitting method. The developed model can be used to estimate total stem volume, merchantable volume to any merchantability diameter limit at any height, and (possibly) height of any diameter based on only easily measurable parameters such as diameter at breast height and total tree height for the species analysed.

Keywords: *Acacia mangium*, compatible volume, estimation model, taper, timber volume

MODEL YANG KOMPATIBEL UNTUK PENDUGAAN VOLUME DAN TAPER BATANG HUTAN TANAMAN Acacia mangium Willd. *Tulisan ini mempelajari penyusunan model penduga volume yang kompatibel untuk jenis* Acacia mangium *Willd. berdasarkan data dari 279 pohon contoh yang ditebang dari areal tegakan hutan tanaman* A. mangium *di Sumatera Selatan, Indonesia. Model ini terdiri dari model volume total dan model taper batang, yang kompatibel dalam arti volume total yang diperoleh dari integrasi model taper sama dengan volume yang dihitung dengan model volume total. Beberapa fungsi persamaan umum volume total diuji, termasuk faktor bentuk konstan, variabel gabungan, variabel gabungan umum, logaritmik, logaritmik umum dan variabel Honer yang ditransformasi. Hasil pengujian menunjukkan bahwa model logaritmik merupakan model terbaik dan dipilih sebagai dasar untuk menurunkan model taper. Prosedur statistik yang sesuai digunakan dalam penyusunan model untuk mengatasi masalah heteroskedastisitas dan autokorelasi yang berkaitan dengan fungsi persamaan volume dan taper. Metode* fitting *secara simultan dari* Seemingly Unrelated Regression *(SUR) menghasilkan estimasi parameter dan statistik kelayakan model yang lebih baik dibandingkan dengan metode* fitting *secara independen dengan tetap menjamin konsistensi numerik diantara model-model komponen dan mengurangi total kuadrat error. Model yang dikembangkan dapat digunakan untuk menduga volume batang total, volume kayu komersial sampai ke batas diameter tertentu yang dapat diperdagangkan, diameter pada setiap ketinggian, dan (memungkinkan) tinggi dari setiap diameter, hanya berdasarkan parameter yang mudah terukur seperti diameter setinggi dada dan tinggi pohon total untuk jenis yang dianalisis.*

Kata kunci: Acacia mangium, *volume yang kompatibel, model pendugaan, taper, volume kayu*

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I. INTRODUCTION

Acacia mangium Willd. has been the main species planted in the industrial forest plantations in Indonesia. The wood of *A. mangium* has properties that potentially make it acceptable for a wide range of end-uses, including pulp, veneer and plywood, as well as for sawn timber and other products (Abdul-Kader & Sahri, 1993; Krisnawati, Kallio, & Kanninen, 2011). The wood harvested from *A. mangium* plantations may be merchandised to satisfy the demand for a variety of products. Consequently, the predictions of these product volumes are often more important than total tree volumes. As the standard of merchantability may also change for the pulp and paper industries and the sawmills that may utilise the wood, it is desirable to have a volume model that can predict volume to any specified upper stem diameter, rather than total stem volume model which does not give quantitative information on the amount of wood specified for any particular utilisation standard.

In the development of stem volume estimation models, there are three general methods that can be used to estimate stem volume to any merchantable limit. The first approach is to develop a model for predicting stem volume to a fixed top diameter (Bi & Hamilton, 1998; Tewari & Kumar, 2003; Krisnawati & Bustomi, 2004). This is effective but inflexible if merchantability standards change. The second approach is to develop a volume ratio model that predicts merchantable volume to any specified height limit as a percentage of total stem volume (Reed & Green, 1984; Bi, 1999; Teshome, 2005). The third approach is to develop a stem taper model and obtain estimates of the merchantable volume through integration (Jiang, Brooks, & Wang, 2005; Özçelik & Brooks, 2012; Navar, Rodriguez-Flores, F. J. & Dominguez-Calleros, 2013). Both the second and third approaches eliminate the need for separate volume models for differing merchantability standards as in the first approach. The second approach is easy to use and develop; however, the third approach is generally preferred as this also allows estimation of diameter at a given height (Dieguez-Aranda, Castedo-Dorado, Alvarez-Gonzalez, & Rojo, 2006). The third approach has been considered to be most accurate for estimating the volume to any merchantable limit (Kozak, 2004; Jiang et al., 2005).

A wide range of taper models exists in the literature (e.g. Fang & Bailey, 1999; Fang, Borders, & Bailey, 2000; Sharma & Zhang, 2004; Jiang et al., 2005; Özçelik & Brooks, 2012; Navar, Rodriguez-Flores, F. J. & Dominguez-Calleros, 2013), but their use in Indonesia is still not quite common. Different standard volume models and volume tables are still the most common tools used for estimating the volume of the tree species in Indonesia. The prediction of merchantable volume is usually accomplished by fitting a separate regression model for each merchantability limit (i.e. the first approach). Thus, for a single tree population of a species, there may be three different models for predicting three different merchantable volumes, say, to 4 cm, 7 cm and 10 cm upper stem diameters. The development of separate models for each set of merchantability limits may not only require considerable effort but also the models may not perform satisfactorily when considered together. A few studies have been conducted in Indonesia on the development of taper models for other species (Krisnawati & Wahjono, 2003; Harbagung & Krisnawati, 2009); however, additional work is needed in this area to improve volume estimation.

For *A. mangium* plantations, some volume tables and models with fixed merchantability limits (i.e. 4 cm and 7cm) have been developed in different regions in Indonesia, as summarised in Krisnawati et al. (2011). These include those developed by Sumarna and Bustomi (1986), Bustomi (1988), Wahjono, Krisnawati, and Bustomi (1995), and Krisnawati, Wahjono, and Iriantono (1997) but they may not be sufficient for estimating volume in the currently changing product and market conditions. In addition, they were developed using data with very limited range of tree sizes and ages (e.g. 5 years only). A more flexible and better model therefore needs to be developed for *A. mangium* plantations that covers a wider range of ages and tree sizes and allows prediction of merchantable volume at any specified upper stem diameter.

Ideally, a tree volume estimation model should be compatible, in which the tree volume calculated by a total volume model should be equal to that computed by integration of the stem taper model from the ground to the top of the tree (Clutter, 1980). A simple method that results in compatible, accurate predictions of stem volume and taper of the tree would thus be very useful for practical forest management. The objective of this study was to develop a compatible estimation model of stem volume and taper for *A. mangium* plantations which provide the best possible fit for total stem volume and taper models. The procedure of how to derive a compatible taper and merchantable volume model is described hereafter.

II. MATERIAL AND METHOD

A. Study Site

This study was conducted in the industrial forest plantation area of PT. Musi Hutan Persada in South Sumatra, Indonesia, with *A. mangium* as the main species planted. The overall study site is topographically located at an attitude ranging from approximately 60 to 200 m above sea level. The topography is mostly flat to moderately undulating (0 - 8% in slope) but in some areas is rolling (8 - 15% in slope).

In general, the climate condition in South Sumatra is well suited to *A. mangium* plantations, with even rainfall distribution and relatively constant, warm temperature. In particular, the study area has a lowland humid environment with the average daily temperature of 29°C, ranging from 22 to 33°C. The average relative humidity varies from 56% in the dry season to 81% in the rainy season, with the average annual rainfall ranges from 1890 to 3330 mm.

The soils are derived mainly from sedimentary rocks consisting of tuff, sandy tuff, sandstone and claystone, with a very small portion from volcanic materials. The majority of the soils belong to red-yellow podsolic group (ultisol and oxisol), and are inherently acid and poor in nutrients and have low pH value and low base saturation (Hardiyanto, Anshori, & Sulistyono, 2004).

B. Data Description

Data for this study were obtained from 279 sample trees harvested from *A. mangium* unthinned stands with the planting spacing of 3x3 m. The trees were selected to represent the range of ages, diameter at breast height (DBH) and total tree height. The ages of the sample trees averaged 5.6 years and ranged from 2 to 9 years; DBH averaged 16.3 cm and ranged from 5.7 to 28.8 cm; and total tree height averaged 19.3 m and ranged from 4.7 to 31.5 m. Size distribution of the sample trees based on both

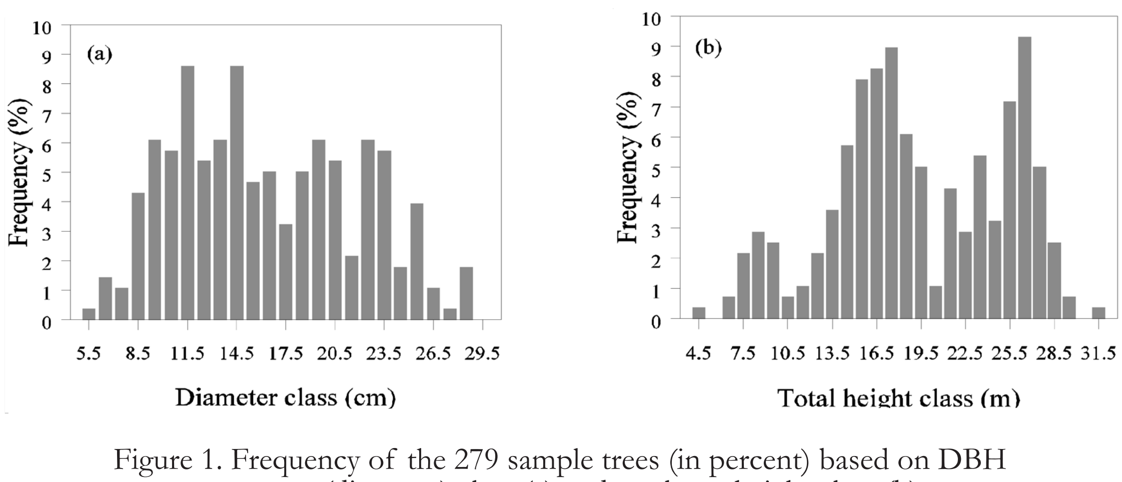

Figure 1. Frequency of the 279 sample trees (in percent) based on DBH (diameter) class (a) and total tree height class (b)

DBH and total tree height classes are shown in Figure 1. The 279 sample trees were split randomly into two data sets by age and 1-cm DBH classes at a ratio 3:1 (209 sample trees were used for model fitting and 70 sample trees were used for model validation).

Before felling, each sample tree was measured for DBH, and after felling, for total tree height. Stump heights were measured and averaged about 10 cm (0.1 m). The felled trees were then cut into 1 m sections, starting from the stump to a top diameter of approximately 4 cm. Each section was measured for diameter over and under bark at the large- and small-end of the sections. The bark thickness was measured to differentiate between the volume to be harvested (over bark) and the volume available for utilization (under bark). From the 279 sample trees, there were 4538 sections available with the number of sections varying from 4 to 26 per tree.

Volumes for each section of each sample tree were calculated using standard formulae applicable to typical tree shapes. The sectional volumes from stump cut to tip were determined using Smalian's formula assuming a frustum of a second degree paraboloid while the volume of the top section was calculated assuming the tip as a cone (Husch, Beers, & Kershaw, 2003). Summation of the volumes of each section gave total volume of each sample tree. Summation from the base to any section provided the merchantable volume to the specific small-end diameter (top diameter) of that section. These volumes are referred to as the "true" stem volume of the tree, although they may differ from the real volume as would be obtained through water displacement methods (e.g. Martin, 1984).

C. Compatible Stem Volume and Taper Models

Compatibility in this study means that the total stem volume, obtained from the volume model is equal to the stem volume derived by integrating the taper model for all trees with the same diameter at breast height and total tree height. There are two approaches for constructing a compatible model: the volume-based model and the taper-based model (Munro & Demaerschalk, 1974). The volume-based model fits a volume model, and then derives the corresponding stem taper model based on the volume model. The coefficients of the taper model are conditioned such that volume, obtained by the volume model is equal to the volume derived by integrating the taper model for all trees. Examples of such an approach are the models developed by Byrne and Reed (1986), and Mc Tague and Bailey (1986). The taper-based model develops a taper model, and the compatibility of the model is ensured by imposing the condition on the coefficients so that integration of the taper model provides the total volume of the tree. Examples of such an approach are the models of Fang and Bailey (1999), and Fang et al. (2000).

In this study, the volume-based model was applied. This approach was selected due to lower biases (Munro & Demaerschalk, 1974) and was more tractable via a geometric approach (Byrne & Reed, 1986). The taper model was derived from the total stem volume model, applied to the tree from the top to down and constrained to predict the same total stem volume when integrated as a direct volume prediction method for the total stem. This constraint was imposed by defining the limits of integration of the taper and total volume models. Stem diameter is equal to zero when distance from the top of the tree to the merchantability limit is equal to total tree height, ensuring compatibility between the merchantable and total volume models.

D. Development of Total Stem Volume Model

To determine the most appropriate model for estimating the total stem volumes both for over bark (*Vob*) and under bark (*Vub*), six individual stem volume model forms that have been used in various studies for predicting individual stem volume in different forest regions and forest types (Clutter, Fortson, Pienaar, Brister, & Bailey, 1983; Husch et al., 2003) were tested.

Table 1. Individual stem volume models tested as the basis for deriving the taper model

Model	Name	Expression
V-1	Constant form factor	$V = a_0 D^2Ht$
V-2	Combined variable	$V = a_0 + a_1D^2Ht$
V-3	Generalized combined variable	$V = a_0 + a_1D^2 + a_2Ht + a_3D^2Ht$
V-4	Logarithmic	$V = a_0D^{a1}Ht^{a2}$
V-5	Generalized logarithmic	$V = a_0 + a_1D^{a2}Ht^{a3}$
V-6	Honer transformed variable	$V = \frac{D^2}{(a_0 + a_1Ht^{-1})}$

In order to choose a model form which provides the most accurate stem volume prediction, all six candidate stem volume models (Table 1) were fitted for over bark and under bark stem volume using least squares regression method. Studentised residual plots showed an uneven spread of residuals for all models, with the variance of residuals increasing with the predicted value, indicating the presence of heteroscedasticity of error. One example of the heteroscedasticity problem is demonstrated for Model V-4 (logarithmic form) in Figure 2(a).

This problem has commonly occurred in other studies fitting regression models to stem volumes (e.g. Williams & Gregoire, 1993; Williams & Schreuder, 1996; Bi & Hamilton, 1998). To correct for the heteroscedastic errors, the solution may be to weight each observation during the fitting process by the inverse of its variance (σ_i^2). Different assumptions about the nature of heteroscedasticity in the construction of volume models may be made; however, the error variance of the *i*th individual is often modelled as a power function of diameter and height, $\sigma_i^2 = (D_i^2 Ht_i)^k$ (Furnival, 1961; Clutter et al., 1983). The most reasonable value of the exponential term *k* should provide the most homogenous studentised residual plot (Huang, 1999), which can be obtained by iteratively testing different values of *k* (e.g. from 0.1 to 2). All models (except Model V-4) were refitted using weighted least squares regressions using a weighting factor, $(D_i^2 Ht_i)^{-k}$, with the optimum values of *k* was selected to the nearest interval of 0.1. In this case, logarithmic transformation to all variables was used to solve the problem

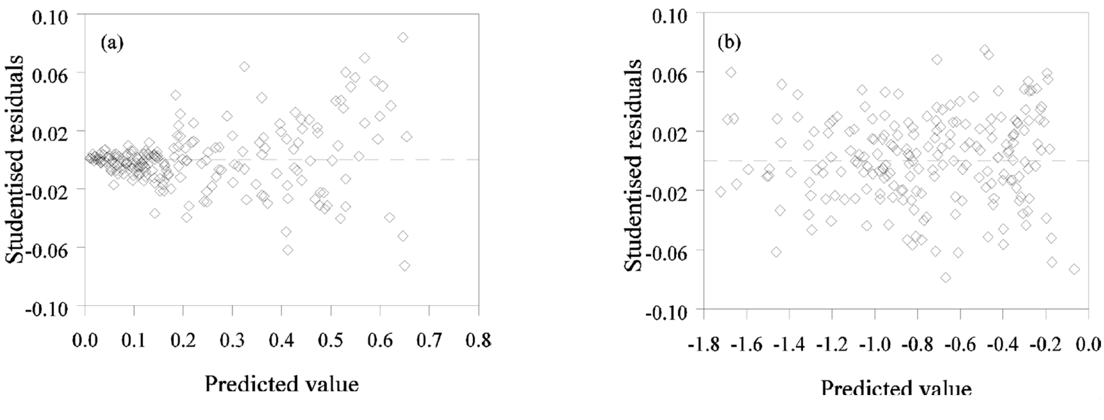

Figure 2. Studentised residuals plotted against predicted values fitted using Model V-4 for over bark volume before transformation (a) and over bark volume after logarithmic transformation (b)

of unequal error variance as well as to attain linearity. Transforming variables in this way produces the model which has a more equal error variance. As illustrated in Figure 2(b), the weighted residuals of Model V-4 show a more even spread when plotted against predicted values.

It should be noted that the use of weighted least squares regression changes the estimates of the parameters and the standard errors of the estimates relative to the values obtained in the absence of weighting (Ratkowsky, 1990). As the usual index of fit could not be applied to compare the candidate total stem volume models that have different dependent variables (after weighting or transformation), Furnival's Index of fit (Furnival, 1961) was used to select the best model for predicting total stem volume. Based on the Furnival's Index of fit, the logarithmic model (Model V-4) was determined to be best for estimating total stem volume both over bark and under bark:

$$\log V = a_0 + a_1 \log D + a_2 \log Ht \qquad (1)$$

A total stem volume model of this type has also been used previously by many studies for estimating stem volumes for *A. mangium* plantations (e.g. Bustomi, 1988; Wahjono et al., 1995; Krisnawati et al., 1997) as well as for other species (e.g. Fang & Bailey, 1999; Fang et al., 2000; Cecilia et al., 2014). This model was also consistently the best in the validation data set. The model was then used as the basis for deriving the taper and merchantable volume models in order to invoke the compatibility constraint.

E. Derivation of Compatible Taper Model

The stem volume model of Eq.(1) can be converted into a stem taper model as follows (e.g. Demaerschalk, 1973; McTague & Bailey, 1986):

$$\log d = b_0 + b_1 \log D + b_2 \log Ht + b_3 \log l \qquad (2)$$

where d is upper stem diameter over bark or under bark (cm), D is DBH (cm), Ht is total tree height (m), l is distance from the tip of the stem to the merchantability limit (m), and b_0, b_1, b_2, b_3 are parameters to be estimated

Mathematically, Eq.(2) can be expressed as:

$$d = 10^{b0} D^{b1} Ht^{b2} l^{b3} \qquad (3)$$

or in a squared form:

$$d^2 = 10^{2b_0} D^{2b_1} Ht^{2b_2} l^{2b_3} \qquad (4)$$

The use of d^2 as dependent variable (Eq.(4)) is mathematically more convenient than d (Eq.(3)) in taper models (Clutter, 1980). The volume of a single tree from the taper model (V_2) of Eq.(4) is calculated by integration of d with respect to l:

$$V_2 = \frac{\pi}{4} 10^{-4} \int_0^{Ht} 10^2 dl \qquad (5)$$

Substitution of Eq.(4) for d^2 into Eq.(5) results in:

$$V_2 = \frac{\pi}{4} 10^{-4} \int_0^{Ht} 10^{2b_0} D^{2b_1} Ht^{2b_2} l^{2b_3} dl \qquad (6)$$

$$V = \left(-10^{\;4} 10^{2b} D^{2b_1} Ht^{2b_2} \right) \int^{Ht} l^{2b} dl$$

$$V_2 = \left(\frac{\pi}{4} 10^{2b_0 - 4} D^{2b_1} Ht^{2b_2} \right) \frac{1}{2b_3 + 1} \left[l^{2b_3 + 1} \right]_0^{Ht}$$

when $l = Ht$, that is, the distance from the tip to the upper stem diameter is equal to the total tree height, the above model:

$$V_2 = \frac{\pi}{4} 10^{2b_0 - 4} D^{2b_1} Ht^{2b_2} \frac{1}{2b_3} Ht^{2b_3 + 1}$$

$$V_2 = \frac{\pi}{4} 10^{2b_0 - 4} D^{2b_1} Ht^{2b_2 + 2b_3 + 1} \frac{1}{2b_3 + 1}$$

Let, $\frac{\pi}{4} \frac{10^{2b_0 - 4}}{2b_3 + 1} = C$ Eq.(6) then becomes:

$$V^2 = CD^{2b_1} Ht^{2b_2} + 2^{b_3} + 1 \qquad (7)$$

Eq.(7) can be transformed into a logarithmic form:

$\log V2 = \log C + 2b_1 \log D + (2b_2 + 2b_3 + 1) \log Ht$ (8)

Based on the compatibility constraint, that is, V_1 (volume derived from the total volume model, Eq.(1)) is equal to V_2 (volume obtained from the taper model, Eq.(8)), the coefficients of these two models are conditioned such that:

$a_0 = \log C$ (9)

$a_1 = 2b_1$ (10)

$a_2 = 2b_2 + 2b_3 + 1$ (11)

The coefficients of the taper model (Eq.(2)) were expressed in terms of the coefficients of the volume model (Eq.(1)), i.e. a_0, a_1, a_2 and one 'free parameter' (p), which is a unique value for a given set of taper data. This parameter (p) expresses the variability of d along the stem of a tree and depends on the D, Ht and l.

Let $2b_3 + 1 = pa_2$ (12)

Eq.(9) can be rewritten as:

$$a_0 = \log C = \log \left[\frac{\pi 10^{2b_0 - 4}}{4 p a_2} \right] \quad (13)$$

Solving for b_0 results in:

$$b_0 = \frac{1}{2} \left[\log \left[\frac{4}{\pi} 10^{a_0 + 4} p a_2 \right] \right] \quad (14)$$

Eq.(10) can be rewritten as:

$$b_1 = \frac{a_1}{2} \quad (15)$$

Eq.(11) can be rewritten as: (16)

$$b_2 = \frac{a_2 (1 - p)}{2}$$

The coefficient of b_3 can be derived from Eq.(11):

$$b_3 = \frac{pa2 - 1}{2}$$

F. Estimation of Merchantable Volume Model to Any Specified Upper Stem Diameter

To predict merchantable volume of a tree to any upper stem diameter limit, the compatible taper model (Eq.(3)) was used. Algebraically, Eq.(3) can be rearranged to estimate the distance l from top of the stem to the point of merchantability limit (d): (17)

$$l = 10^{-b_0/b_3} d^{1/b_3} D^{-b_1/b_3} Ht^{-b_2/b_3}$$

The volume to a specific distance l from tip of the stem (V_l) can be calculated as follows: (18)

$$V_1 = CD^{2b_1} Ht^{2b_2} l^{2b_3+1}$$

The compatible taper model after being integrated with respect to l, provides the total volume (Vt) when total tree height Ht equals a given distance l as derived in Eq.(7): (19)

$$V_1 = CD^{2b_1} Ht^{2b_2+2b_3+1}$$

The merchantable volume to any merchantability limit d (V_m) is therefore the difference between V_{ta} and V_l: (20)

$$V_m = V_t - V_l$$

Substituting the right sides of Eqs.(18) and (19) into Eq.(20) results in: (21)

$$V_m = CD^{2b_1} Ht^{2b_2} [Ht^{2b_2+1} - l^{2b_3+1}]$$

Substituting l from Eq.(17) into Eq.(21) provides the merchantable volume to any merchantability limit (d):

$$V_m = CD^{2b_1} Ht^{2b_2} \left[Ht^{2b_3+1} - \left[10^{-b_0 \left[\frac{2b_3+1}{b_3}\right]} d^{\left[\frac{2b_3+1}{b_3}\right]} D^{-b_1 \left[\frac{2b_3+1}{b_3}\right]} Ht^{-b_2 \left[\frac{2b_3+1}{b_3}\right]} \right] \right]$$

G. Parameter Estimation of the Compatible Volume and Taper Models

The compatible model analysed has two components: a total volume model (V = f (DBH, Ht)) and a taper model (d = f (DBH, Ht, l)). The model was composed by the endogenous variables (variables included on the left hand side of equation) V and d, which are assumed to be determined by the model structure and exogenous variables D, Ht and l, which are independent variables. To ensure compatibility between the total volume and the taper models, two methods can be used for fitting the volume-based model in this study. The first method is to fit the total volume model using the total volume observations, and then algebraically solve for the parameters of the taper model based on the previously obtained parameters from the fitted volume model. The second is to estimate all the parameters of the model (both the volume and taper models) simultaneously, in which the parameters were expanded by the compatibility relationship when programming the models prior to fitting.

Estimation of the parameters for both over and under bark measurements was carried out using the MODEL procedure of SAS/ETS model (SAS Institute Inc., 2005). For the first method, ordinary least squares estimation procedure was applied. For the second, the seemingly unrelated regression (SUR) technique was used to fit the model. The SUR technique was considered since both the total volume and taper models seem unrelated (none of the endogenous variables in one equation of the model appears as an independent variable in another equation), but the equations are related through the correlation in the errors. A set of equations that has contemporaneous cross-equation error correlation (i.e. the error terms in the regression equations are correlated) is called a seemingly unrelated regression (SUR) (Judge, Hill, Griffiths, Lütkepohl, & Lee, 1988).

It should be noted that in the compatible model composed by a total volume and a taper model, the number of observations in each model is not equal. There is more than one diameter observation for each tree but only one observation for the total stem volume. However, simultaneous fitting of both models requires the number of observations of the two endogenous variables to be equal. To overcome this problem, a special structure of the data was created by assigning the total volume to each diameter observation on the same tree.

Since the taper data comprise multiple stem diameter measurements along each sample tree, autocorrelations may exist among the residuals, which violates the assumption of independent error terms. To check for the possible autocorrelation, graphs representing residuals versus residuals of the adjacent section within the same tree were examined visually. Appropriate fits for the models with correlated errors were done by including the autoregressive error structure in the MODEL procedure of SAS/ETS system (SAS Institute Inc., 2005).

H. Model Evaluation

Performance of the models of each fitting method was evaluated based on the statistical properties such as asymptotic t-statistics for significance of the parameters, standard error of coefficient (SE), root mean squared error (RMSE), adjusted coefficient of determination (R^2adj) of the model. In addition, the common statistics of average bias (i.e. observed - predicted) and standard error of predictions were calculated to evaluate the performances of the compatible volume and taper models. Since the merchantable volume model was derived from the compatible stem volume and taper model, the possible bias and standard error of the model predictions were also examined. The accuracy of these predictions was evaluated over the entire range of the validation data set. The performance of the models in different parts of the stem and for various sizes of tree (i.e. by DBH and tree height classes) was also examined.

A commonly used method for evaluating prediction accuracy within specified diameter or total height classes is sorting the prediction errors according to DBH or total tree height, then dividing them into intervals of equal width and calculating relevant statistics on bias and standard error of the predictions. These statistics are very important for showing areas or tree size classes for which the compatible volume and taper model and its implied merchantable volume model provide especially good or poor predictions (Kozak & Smith, 1993; Kozak, 2004).

III. RESULT AND DISCUSSION

A. Estimation of the Compatible Volume and Taper Model

Parameters in the compatible model were estimated by two different methods. In the first method the logarithmic total volume model was fitted independently using the total volume observations. Following this, the estimated parameters were substituted into the taper model and the remaining parameter

Table 2. Parameter estimates, standard errors and related fit statistics of "independent" (first method) and simultaneous (second method) fittings of the compatible volume and taper models for both over bark and under bark

Model	Parameter	Estimates	*SE*	*t*	*p*-value	*RMSE*	R^2_{adj}
Independent fitting							
log*Vob*	a_0	-4.2117	0.019	-214.36	0.000	0.033	0.994
	a_1	1.734	0.0268	64.59	0.000		
	a_2	1.081	0.0276	39.10	0.000		
log*dob*	b_0	0.1339	0.007	19.13	0.000	0.040	0.954
	b_1	0.867	0.0085	102.49	0.000		
	b_2	-0.644	0.0102	-63.32	0.000		
	b_3	0.685	0.0031	222.99	0.000		
log*Vub*	a_0	-4.3784	0.025	-177.18	0.000	0.033	0.992
	a_1	1.744	0.0302	57.81	0.000		
	a_2	1.163	0.0296	39.33	0.000		
log*dub*	b_0	0.0413	0.005	8.43	0.000	0.039	0.949
	b_1	0.872	0.0094	92.76	0.000		
	b_2	-0.554	0.0108	-51.18	0.000		
	b_3	0.635	0.0035	182.09	0.000		
Simultaneous fitting							
log*Vob*	a_0	-4.197	0.0071	-590.03	0.000	0.011	0.999
	a_1	1.736	0.0071	322.97	0.000		
	a_2	1.0734	0.00259	414.63	0.000		
log*dob*	b_0	0.14	0.003	40.66	0.000	0.031	0.973
	b_1	0.8678	0.00269	322.97	0.000		
	b_2	-0.6393	0.00154	-414.63	0.000		
	b_3	0.676	0.0028	238.35	0.000		
log*Vub*	a_0	-4.27	0.008	-530.52	0.000	0.012	0.999
	a_1	1.778	0.0064	278.89	0.000		
	a_2	1.04	0.003	343.49	0.000		
log*dub*	b_0	0.099	0.0039	25.37	0.000	0.032	0.967
	b_1	0.889	0.0032	278.89	0.000		
	b_2	-0.6213	0.00181	-343.49	0.000		
	b_3	0.643	0.0033	193.20	0.000		

Notes: *Vob* is stem volume over bark (m^3), *Vub* is stem volume under bark (m^3), *dob* is upper stem diameter over bark (cm) and *dub* is upper stem diameter under bark (cm)

of the model was then estimated. In the second method, all parameters in the model were estimated simultaneously using the SUR technique. In this case, parameters in the total volume model were estimated in such a way that they not only minimised the squared error in the total volume, but also minimised the squared error for the taper model. Due to the longitudinal nature of the taper data used for model fitting, a trend in residuals as a function of residuals of the adjacent section within the same tree was apparent in the models analysed (plots not presented here). This has also been found in similar studies for other species (Rojo, Perales, Sánchez-Rodríguez, Álvarez-González, & Gadow, 2005; Corral-Rivas, Diéguez-Aranda, Rivas, & Dorado, 2007). After correcting for autocorrelation using a first order autoregressive error structure, the trends in residuals disappeared. The final parameter estimates and their corresponding standard errors for the models fitted using the two methods are presented in Table 2.

As can be seen in Table 2, the corresponding parameter estimates from the two methods were very similar and all parameters in the models were found to be significant (p-value< 0.01). All parameter estimates are logical and ensure compatibility between the volume and taper models. Goodness-of-fit statistics show that the compatible models fit both volume and upper stem diameter data reasonably well. For example, more than 94% (R^2adj) of the variation about the values of d and V for both over and under bark is explained by the model.

With the "independent" fitting (first method), it is quicker to achieve convergence on the parameter estimates, and may provide the best estimate of the total volume. While independent estimation (for total volume) can lead to more accurate and precise prediction of total stem volume, it may increase the bias and standard error for the taper prediction, although the amount can be small. As indicated in Table 2, the standard errors of the coefficients (*SE*) from the independent fitting method are larger than those from the simultaneous fitting method, suggesting that the estimates which result from such an algebraic procedure are not statistically efficient (Burkhart & Sprinz, 1984; Reed & Green, 1984). This is because the parameters in the total volume model are obtained by minimising the sum of squares error of total volume only, but does not ensure minimal error in taper model.

Inspection of the individual component sums of squared errors for the model showed that the simultaneous fitting method reduced the total model squared errors, which simultaneously minimised both volume and taper prediction errors. Fitting both models simultaneously also improved the fit. For example, the root mean squared error (*RMSE*) in total stem volume over bark fell from 0.033 for the "independent" method to 0.011 (66.7% in Table 2) when the simultaneous estimation was used. The corresponding decrease was 44.4% (from 0.033 to 0.012) for volume under bark (Table 2). For the taper model, when the model was fitted simultaneously the root mean squared error fell by 7.4% (from 0.040 to 0.031) and 7.8% (from 0.039 to 0.032) for upper stem diameter over bark and under bark, respectively (Table 2). Based on these results, simultaneous fitting was the more appropriate method for parameter estimation in this study. All figures, tables and discussion that follow will then be based on the parameters estimated by simultaneous fitting (second method).

B. Predicting Taper, Total and Merchantable Stem Volume

It should be noted that the compatible model of both volume and taper models was fitted using logarithmic transformation. To predict values in the original unit, a correction factor may need to be applied to correct the proportional bias in the estimate of volume or taper introduced by the back-transformation. In this study, the correction factor was calculated as the ratio of the mean of sample values to the mean of back-transformed predicted values from the regression following procedure of Snowdorn (1991), i.e. 1.0012 and 1.0029 (for total volume over and under bark, respectively), and 1.0029 and 1.0013 (for upper stem diameter over and under bark, respectively).

Taking into account the correction factors, the following models may be used to predict total volume over bark (*Vob*) and total volume under bark (*Vub*):

$$\hat{V}ob_{tot} = 0.0000636\, D^{1.736}\, Ht^{1.0734} \qquad (23)$$

$$\hat{V}ub_{tot} = 0.0000542\, D^{1.778}\, Ht^{1.04} \qquad (24)$$

The corresponding taper volume models that can be used to predict the diameter merchantability limit (d) for both over bark (*dob*) and under bark (*dub*) are:

$$\hat{d}ob = 1.384\, D^{0.8678}\, Ht^{-0.6393}\, l^{0.676} \qquad (25)$$

$$\hat{d}ub = 1.256\, D^{0.889}\, Ht^{-0.6213}\, l^{0.643} \qquad (26)$$

Using the compatibility relationship between the total stem volume and stem taper models, merchantable volume model were then derived.

Thus, the merchantable volume up to any desired top diameter limit (*d*) can be predicted by the following models:

$$\hat{Vob}_{mer} = 0.0000636\, D^{1.736}\, Ht^{-1.2786} \left(Ht^{2.352} - \left(0.326\, dob^{3.479}\, D^{-3.019}\, Ht^{2.224} \right) \right) \quad (27)$$

$$\hat{Vub}_{mer} = 0.0000542\, D^{1.778}\, Ht^{-1.2426} \left(Ht^{2.286} - \left(0.445\, dub^{3.555}\, D^{-3.161}\, Ht^{2.209} \right) \right) \quad (28)$$

The total stem volume may be regarded as a special case of merchantable volume when the upper stem diameter equals zero ($d = 0$). In this case, the stem volume can be predicted by either Eq.(23) or (27) for volume over bark and either Eq.(24) or (28) for volume under bark, and the results would be identical. Therefore, the merchantable volume model is also compatible with the total volume model.

An example of obtained predicted taper curves for an *A. mangium* tree with DBH = 14.5 cm and total tree height = 20 m using Eq.(25) for diameter over bark (*dob*) and Eq.(26) for diameter under bark (*dub*) are illustrated in Figure 3(a). The differences between *dob* and dub decrease with stem height, consistent with bark thickness becoming negligible at the very upper stem. The corresponding results of the stem volume curves predicted using Eq.(27) for *Vob* and Eq.(28) for *Vub* are also quite reasonable in appearance (Figure 3(b)), with the difference between the *Vob* and *Vub* being about 12.7%. For practical purpose, the prediction of volume and proportions of bark will become important as interest increases in efficient use of timber harvesting residues. Therefore, an important distinction should be made between *Vob* and *Vub*. The *Vob* model can be used to estimate the over-bark volume to be harvested and the *Vub* model can be used to estimate the under-bark volume available for utilization.

C. Model Evaluation

In addition to statistical properties presented in Table 2, the prediction accuracy of the compatible model of taper and total volume models as well as the merchantable volume model were examined based on biases and their standard errors of the predictions for both over and under bark (Table 3). The overall mean biases for both total volume and taper were found to be positive (for both over and under bark), indicating that the models are slightly under predicting. The positive mean bias was also found for merchantable volume. These results were reasonable since the merchantable volume model were derived algebraically from the compatible taper and total volume models; if the total volume and the taper (stem diameter) are underestimated then merchantable volume would be expected to be underestimated too. However, these biases and their corresponding standard errors of the predictions were

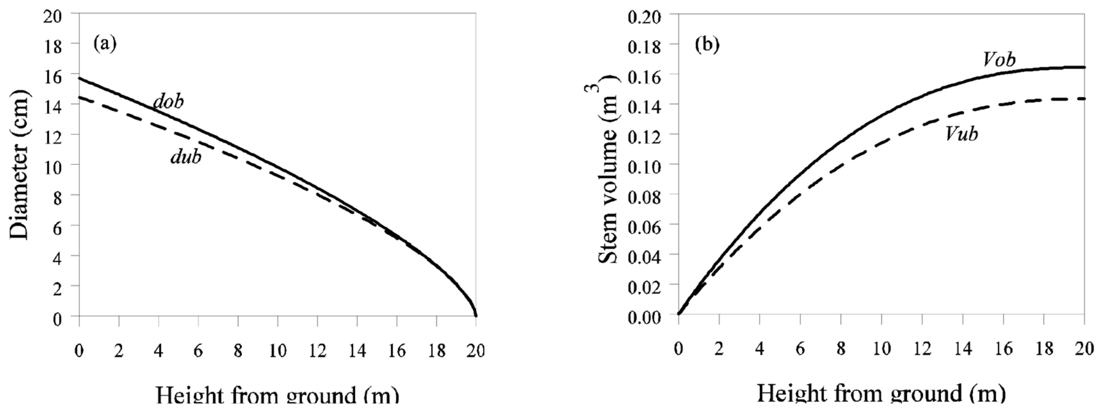

Figure 3. Examples of stem taper (a) and volume (b) curves for *A. mangium* tree with DBH = 14.5 cm and total tree height = 20 m for both over bark (*ob*) and under bark (*ub*)

Table 3. Overall mean bias and standard error of the predictions for the total volume, taper (stem diameter) and merchantable volume models

Model	Bias		Standard errors of predictions	
	over bark	under bark	over bark	under bark
Total volume (m^3)	0.0012	0.0009	0.0272	0.0135
Stem diameter (cm)	0.1019	0.0095	1.1232	0.8213
Merchantable volume (m^3)	0.0233	0.0113	0.0652	0.0381

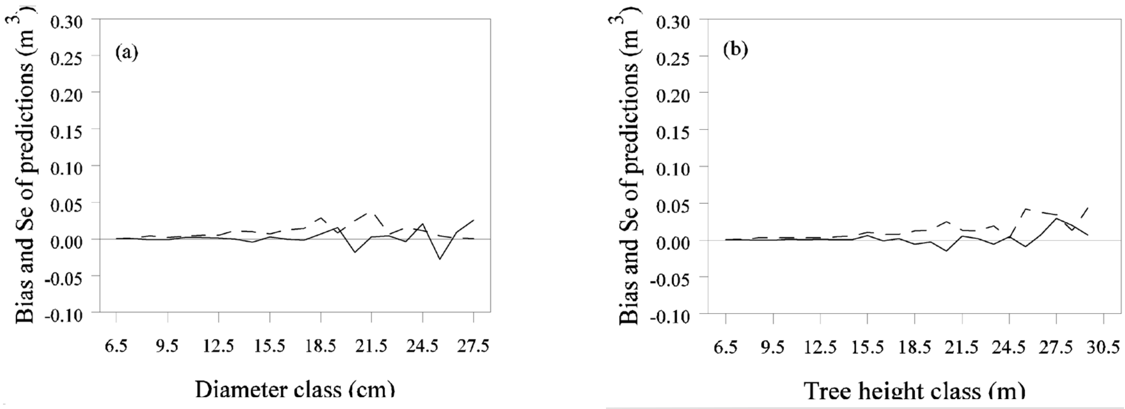

Figure 4. Average bias (*solid line*) and standard errors of the predictions (*dashed line*) for total stem volume over bark at different DBH class (a) and tree height class (b)

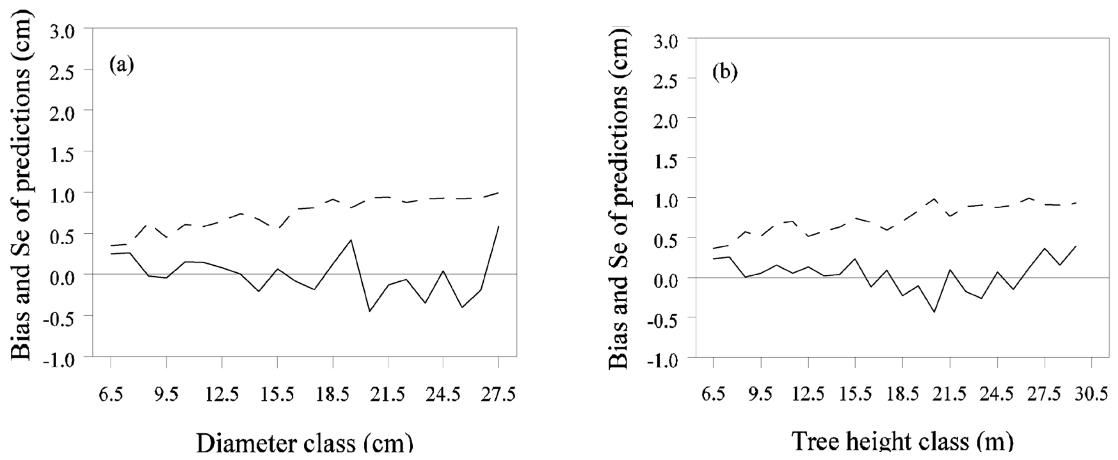

Figure 5. Average bias (*solid line*) and standard errors of the predictions (*dashed line*) for stem diameter over bark at different DBH class (a) and tree height class (b)

generally small and unlikely to be of practical importance.

Prediction accuracy was also evaluated over the entire diameter and height ranges of the data. The example of the average biases and their standard errors of the predictions for total stem volume over bark at different DBH and total tree height classes are presented in Figure 4. These graphs show that the mean biases and standard error of predictions were generally small and stable across DBH and total height classes. There were similar results (not presented

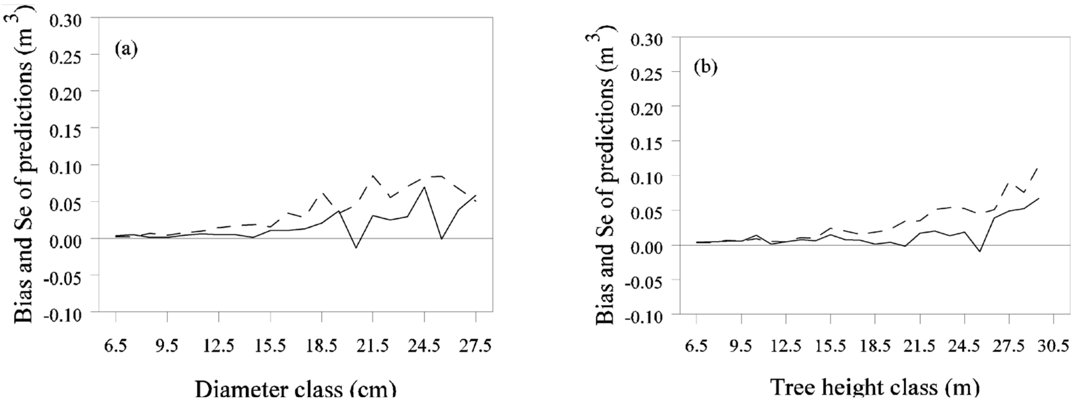

Figure 6. Average bias (*solid line*) and standard errors of the predictions (*dashed line*) for merchantable stem volume over bark at different DBH class (a) and tree height class (b)

here) for total stem volume under bark. These results suggested that both total stem volume models (Eqs.(23) and (24)) were satisfactory for predicting total stem volume over bark and stem volume under bark, respectively, with acceptable level of bias over the entire diameter and total tree height ranges of the data.

Similarly, the accuracy of the predictions for taper (stem diameter) and merchantable volume was evaluated over the ranges of DBH and total tree height classes. An example is presented for stem diameter over bark (Figure 5) and merchantable volume over bark (Figure 6). There were no strong trends in the bias and standard errors of the predictions of the stem diameters across DBH and total tree height classes although bias tended to be positive and large for the larger diameter or height classes (Figure 5). Similar pattern is evident for merchantable volume predictions. Although the biases and standard error of the predictions for merchantable volume were slightly higher for trees with larger diameter (Figure 6), this may be due to lack of data regarding bigger trees. Despite this, overall bias and standard errors of the predictions for these models were small and may be considered to be negligible for practical forest management.

These results suggested that both taper and merchantable volume models generally describe well the entire stem profile of *A. mangium* tree, and thus makes it unnecessary to develop segmented taper models for different parts of the stem as has been suggested by several authors (e.g. Max & Burkhart, 1976; Fang et al., 2000). A possible explanation is that the *A. mangium* stems used in this study did not exhibit much butt swell (less neiloidal at the lower stems), which has been shown in some other species to be the main source of the bias, either in taper or in volume models (e.g. Sharma & Zhang, 2004; Jiang et al., 2005; Rojo et al., 2005). National Research Council (1983) also reported that *A. mangium* grown in plantations usually has good stem form, with the main bole usually straight and clear, and butt swell is minimal.

D. Application for Predicting Multiple Products

Stems are usually cut to specified log lengths or diameter limits during harvesting, and more than one log may be cut from the same stem for different products. The compatible tree volume and taper model produced in this study can be used to estimate the portions of these product volumes from the total volume of a single stem. If the diameter at breast height, total tree height, and merchantable top diameter are given, estimates of the portions of these products, such as the amounts of sawtimber and pulpwood, can be calculated. The following example illustrates how Eq.(27) (for volume over bark) can be used to predict the volumes of multiple products from a single stem:

1. Suppose DBH = 28.8 cm and total tree

height = 26 m. Total stem volume over bark would be 0.7175 m^3 (estimated by Eq.(27) with top diameter, *dob* = 0).

2. If merchantable top diameter was specified as 4 cm, the merchantable volume up to 4 cm top diameter would be 0.7167 m^3 (estimated by Eq.(27) with top diameter, *dob* = 4).
3. Merchantable volume specified for sawtimber (e.g. dob = 20 cm) would be 0.5141 m^3 (estimated by Eq.(27) with top diameter, *dob* = 20).
4. The difference between total volume and merchantable volume of sawtimber could be the volumes of pulpwood or fuel wood. If pulpwood is specified to be 4 cm in top diameter limit, the volume of pulpwood would lie between the 20 and 4 cm top diameter limits (i.e. 0.7167 – 0.5141 = 0.2026 m^3).
5. The remaining volume (between 4 and 0 cm in top diameter limit) could be the fuel wood or stay in the stand as residue after harvest (i.e. 0.0008 m^3).

Similar procedures can be repeated to predict volume under bark using Eq.(28).

The above examples demonstrate the advantage of estimating volume through taper models over existing volume models or volume tables. This is due to the ability of taper models to accurately predict diameter over bark or diameter under bark at any given height of individual trees, hence allowing the acquisition of merchantable volume estimates to any desired specification. This benefit has also been reported by Li and Weiskittel (2010).

IV. CONCLUSION

The best compatible model for estimating stem volume and taper developed for *A. mangium* plantations was derived based on the logarithmic function fitted using a simultaneous method of the seemingly unrelated regression. The developed compatible model is efficient and flexible enough to estimate total stem volume, merchantable volume to any merchantability limit, diameter at any height, and (possibly) height of any diameter based on only easily measurable parameters such as diameter at breast height and total tree height. Predicted volumes to various merchantability limits can be obtained using a single model for volume over bark (*Vob*) and volume under bark (*Vub*), respectively, as follows:

$$\hat{V}ob_{mer} = 0.0000636\, D^{1.736}\, Ht^{-1.2786} \left(Ht^{2.352} - \left(0.326\, dob^{3.479}\, D^{-3.019}\, Ht^{2.224}\right)\right)$$

$$\hat{V}ub = 0.0000542\, D^{1.778} \left(Ht^{2.286} - \left(0.445\, dub^{3.555}\, D^{-3.161}\, Ht^{2.209}\right)\right)$$

The model has been shown to perform well for the two data sets (over and under bark measurements) of the total volume as well as merchantable volume. The taper model appears to be sufficient to describe the stem profile of *A. mangium* trees, thus eliminating the need to develop segmented taper models for different parts of the stem.

In stand yield prediction where yield estimates by product category are required, the model will prove to be very useful for estimating total and merchantable volumes of individual trees and thus the total and merchantable volumes expected from the stands. The compatible model produced in this study also provide a major improvement over the previous models for *A. mangium* plantations in Indonesia which were mainly developed based on different standard volume models and is only applicable for estimating stem volume to a fixed top diameter limit.

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Water is a necessary part of every reasons's diet and of all the nutrient a body needs to function, it requires more water each daya than any other nutrients a body needs to function, it requires more water each day than any other nutrient (Whitney & Rolfes, 2011)

Or

Whitney and Rolfes (2011) state the body requires many nutrients to function but highlight that water is of greater importance than any other nutrient.

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