ISSN 2355-7079
E-ISSN 2406-8195
538/AU3/P2MI-LIPI/06/2013

Indonesian Journal of Forestry Research

Vol. 2 No. 1, April 2015

Ministry of Environment and Forestry
Research, Development and Innovation Agency
Indonesia

Indonesian Journal of Forestry Research

Vol. 2 No. 1, April 2015

Annals of the Indonesian Journal of Forestry Research

Indonesian Journal of Forestry Research (IJFR) was first published as Journal of Forestry Research (JFR) on November 2004 (ISSN 0216-0919). The last issue of JFR was Volume 10 Number 2 published on December 2013. The Journal of Forestry Research has been accredited by the Indonesian Institute of Sciences since 2008. The last accreditation was on 21 June 2013 (accreditation number: 538/AU3/P2MI-LIPI/06/2013) which will be valid until 2016. IJFR will be issued in one volume every year including two issues which will be delivered every April and October. This Journal is published by Research, Development and Innovation Agency (FORDA), Ministry of Environment and Forestry, formerly known as Forestry Research and Development Agency, the Ministry of Forestry Republic of Indonesia. The name of publisher has been changed due to the amalgamation of the Ministry of Forestry with the Ministry of Environment into the Ministry of Environment and Forestry, Republic of Indonesia *(Perpres No. 16/2015)*. Consequently, the Forestry Research and Development Agency was transformed into Research Development and Innovation Agency for Forestry and Environment. The logo of the ministry was reformed, accordingly.

Aim and Scope

The journal publishes state of the art results of primary research findings and synthesized articles containing significant contribution to science and its theoretical application in areas related to the scope of Indonesian Forestry Research. Overseas works relevant to Indonesia conditions may be accepted for consideration.

All inquiries and manuscripts should be sent to:

Indonesian Journal of Forestry Research
Sub Bagian Diseminasi, Publikasi dan Perpustakaan
Sekretariat Badan Litbang dan Inovasi
Kementerian Lingkungan Hidup dan Kehutanan
Jl. Gunung Batu No.5 Bogor 16610

Telephone : (0251) - 7521671
Fax : (0251) - 7521671
E-mail : ijfr.forda@gmail.com
Website : http://ejournal.forda-mof.org

Printed in Indonesia

Accredited by the Indonesian Institute of Science

No. 538/AU3/P2MI-LIPI/06/2013

Editorial Team

Acknowledgement

The Indonesian Journal of Forestry Research expresses sincere appreciation and gratitude to reviewers for selflessly contributing their expertise and time to the reviewing process, which is crucial to ensure the quality and substantive impact of the journal. The journal's editors and authors are collectively grateful for the reviewers' efforts in evaluating and assessing the articles submitted for consideration of publication, regardless of the outcome (acceptance or rejection).

International Reviewers

Dr. Su See Lee
Forest Health and Pathology
Forest Research and Institute Malaysia (FRIM), Malaysia

Dr. Yutaka Tamai
Forest Biology, Edible Mushroom, Mycorrhiza
Hokkaido University, Japan

Peer Reviewers

Prof. Dr. Yusuf S. Hadi
Forestry Engineering,
Wood Science and Forest Product Technology
Bogor Agricultural University, Indonesia

Prof. Dr. Lilik B. Prasetyo
Spatial and Landscape Modelling
Bogor Agricultural University, Indonesia

Dr. Prijanto Pamoengkas
Silviculture
Bogor Agricultural University, Indonesia

Dr. Sri Wilarso B.R.
Biotechnology
Bogor Agricultural University, Indonesia

Indonesian Journal of Forestry Research

Vol. 2 No. 1, April 2015

Contents

Indonesian Journal of Forestry Research

ABSTRACTS

ISSN 2355-7079 | Vol. 2 No.1, April 2015

Keywords given are free term. Abstracts may be reproduced without permission or charge

UDC/ODC 630* 176.1:160.2

Gunawan Pasaribu, Totok K.Waluyo and Gustan Pari

ANALYSIS OF CHEMICAL COMPOUNDS DISTINGUISHER FOR AGARWOOD QUALITIES

(ANALISIS SENYAWA KIMIA PENANDA KUALITAS GAHARU)

Gaharu merupakan produk kayu penghasil resin beraroma wangi dari kayu genus Aquilaria dan Gyrinops (Famili: Thymelaeaceae). Pembentukan gaharu merupakan mekanisme pertahanan pohon terhadap suatu gangguan lingkungan atau penyakit. Berdasarkan Standar Nasional Indonesia, gaharu dapat diklasifikasikan menjadi beberapa tingkatan antara lain gubal gaharu, kemedangan, dan serbuk gaharu. Sistem pengkelasan yang ada didasarkan pada warna, berat, dan aroma. Hal ini menunjukkan bahwa sistem pengkelasan kualitas gaharu saat ini masih subyektif. Oleh karena itu dibutuhkan pengkelasan yang lebih obyektif yang berhubungan dengan komposisi kimia dan kadar resin. Tulisan ini menganalisa kualitas gaharu yang berasal dari Provinsi Sumatera Barat meliputi kemedangan C, teri C, kacangan C, dan super AB. Penelitian dimulai dengan pembuatan serbuk gaharu, kemudian diekstraksi dengan teknik soxhlet menggunakan beberapa pelarut organik (n-heksana, aseton, dan methanol). Ekstrak aseton gaharu dianalisa menggunakan GC-MS untuk menentukan komposisi kimia. Hasil penelitian menunjukkan hubungan linear antara peningkatan kadar resin dengan peningkatan kualitas gaharu. Hasil pengujian GC-MS menunjukkan adanya kelompok sesquiterpena pada gaharu kualitas kemedangan C, teri C, kacangan C, dan super AB. Keberadaan senyawa aromadendrene dijumpai pada semua kualitas gaharu; senyawa ini diduga kuat berperan sebagai senyawa kimia penanda gaharu. Semakin tinggi kadar aromadendrene, kualitas gaharunya semakin baik.

Kata kunci: Gaharu, ekstraksi, kadar resin, komponen kimia, aromadendrene

UDC/ODC 630*416.3

Luciasih Agustini, Chris Beadle, Karen Barry and Caroline Mohammed

PHOTOSYNTHETIC RESPONSES OF *Eucalyptus nitens* AT INITIAL STAGES OF ROOT-ROT INFECTION

(RESPON FOTOSINTESIS *Eucalyptus nitens* PADA TAHAP AWAL INFEKSI PENYAKIT BUSUK AKAR)

Penyakit busuk akar merupakan penyakit yang bersifat laten yang dapat menginfeksi tanaman dalam jangka waktu lama tanpa menimbulkan gejala yang dapat diamati. Oleh karena itu, untuk mengetahui karakter perubahan fisiologis sebelum timbulnya gejala penyakit, telah dilakukan percobaan mengenai respons fotosintesis tanaman pada tahap awal infeksi penyakit busuk akar dengan cara menginokulasi anakan pohon *Eucalyptus nitens* dengan pathogen *Armillaria luteobubalina*. Inokulasi buatan dilakukan dengan menggunakan dua strain *A. luteobubalina* dan dua variasi perlakuan akar, yaitu; dilukai dan tidak dilukai. Respons fotosintesis diamati dengan cara mengukur tiga parameter fotosintesis, yaitu: efisiensi fotosistem II (Fv/Fm), kadar klorofil dan laju fotosintesis (Amax). Pengamatan dilakukan selama tujuh bulan. Perbedaan yang signifikan ditunjukkan oleh data efisiensi fotosistem II (rasio Fv/Fm) antara kontrol dengan perlakuan-perlakuan lainnya. Fv/Fm merupakan parameter yang paling sensitif untuk mengindikasikan serangan awal penyakit busuk akar. Adapun parameter kadar klorofil dan laju fotosintesis (A_{max}) menunjukkan nilai yang menurun baik pada tanaman kontrol maupun perlakuan. Perubahan nilai kedua parameter fotosintesis tersebut lebih ditentukan oleh perbedaan musim. Patogen *A. luteobubalina* berhasil diisolasi kembali dari akar *E. nitens* yang menunjukkan penurunan respons fotosintesis. Hal tersebut menunjukkan bahwa penurunan respons fotosintesis berkaitan dengan adanya infeksi awal penyakit busuk akar. Namun diperlukan percobaan dengan waktu pengamatan yang lebih lama, agar perubahan respons fisiologis lainnya dapat terdeteksi.

Kata kunci: *Eucalyptus nitens*, inokulasi buatan, kadar klorofil, laju fotosintesis, efisiensi fotosistem II, busuk akar

UDC/ODC 630*238

Danang S. Adi, Ika Wahyuni, Lucky Risanto, Sri Rulliaty, Euis Hermiati, Wahyu Dwianto and Takashi Watanabe

CENTRAL KALIMANTAN'S FAST GROWING SPECIES: SUITABILITY FOR PULP AND PAPER

(KAYU CEPAT TUMBUH DARI KALIMANTAN TENGAH: KESESUAIANNYA UNTUK BAHAN BAKU PULP DAN KERTAS)

Berdasarkan penelitian sebelumnya terhadap 30 jenis kayu cepat tumbuh dari PT Sari Bumi Kusuma, Kalimantan Tengah menunjukkan terdapat 5 jenis kayu yang berpotensi sebagai bahan baku pulp dan kertas. Panjang serat dari kelima jenis kayu, yaitu *Endospermum diadenum*, *Dillenia* sp., *Adinandra dumosa*, *Adinandra* sp., dan *Nauclea junghuhnii* lebih dari 2.200 µm. Tulisan ini mempelajari potensi penggunaan kelima jenis kayu tersebut untuk bahan baku pulp dan kertas. Hasil penelitian menunjukkan bahwa kelima jenis kayu mempunyai kerapatan medium sampai berat. Berdasarkan penilaian pada dimensi seratnya, kelima jenis kayu dapat diklasifikasikan dalam kelas kualitas satu untuk pulp dan kertas. Berdasarkan kandungan kimia kayunya, *Dillenia* sp. merupakan jenis yang paling potensial sebagai bahan pulp dan kertas karena memiliki panjang serat 3.119 µm, kandungan holoselulosa dan α-selulosa tinggi, serta kandungan lignin yang rendah. *A. dumosa* juga berpotensi karena seratnya terpanjang, namun kandungan lignin terbanyak diantara kelima jenis kayu tersebut. Sedangkan *N. junghuhnii* adalah jenis yang paling rendah potensinya untuk dijadikan bahan baku pulp dan kertas karena rendahnya kandungan holoselulosa dan α-selulosa.

Kata kunci: Kayu cepat tumbuh, karakteristik serat, kerapatan, kandungan kimia, pulp dan kertas

UDC/ODC 630*31:561

Tyas M. Basuki

LEAF AREA INDEX DERIVED FROM HEMISPHERICAL PHOTOGRAPH AND ITS CORRELATION WITH ABOVE-GROUND FOREST BIOMASS

(INDEKS LUAS DAUN (LAI) YANG DIAKSES DARI FOTO HEMISPHERICAL DAN KORELASINYA DENGAN PERMUKAAN BIOMASSA HUTAN)

Indeks luas daun (LAI) merupakan salah satu faktor fisik utama dalam pertukaran energi antara ekosistem daratan dan atmosfer. LAI menentukan proses fotosintesis yang memproduksi biomassa dan berperan penting dalam reflektan hutan, oleh karena itu hubungan antara LAI dan biomassa dari pengukuran lapangan perlu dibangun untuk membentuk persamaan allometrik yang selanjutnya digunakan untuk mengestimasi biomassa di tempat lain. Tulisan ini mempelajari

hubungan antara diameter setinggi dada (DBH) dengan biomassa tajuk (daun; daun + ranting + cabang) dan juga antara LAI dengan biomassa tajuk; serta LAI dengan biomassa total (TAGB). Pengambilan contoh secara destruktif dilakukan untuk membangun persamaan allometrik. Pengukuran DBH dilakukan pada 52 plot di Kalimantan Timur dengan rincian 35 plot untuk membangun model dan 17 plot untuk validasi. Kamera dengan lensa mata ikan digunakan untuk mengumpulkan data LAI. Hasil penelitian menunjukkan korelasi (r) yang tinggi antara logaritmik natural (ln) DBH dengan biomassa tajuk berkisar antara 0,88 sampai 0,98. Koefisien korelasi (r) antara LAI dengan biomassa daun; tajuk (daun + ranting + cabang); dan TAGB secara berurutan adalah 0,742, 0,768, dan 0,772. Peningkatan koefisien determinasi hubungan antara LAI dengan biomassa dapat ditingkatkan melalui pengukuran LAI pada waktu yang tepat yaitu kondisi langit seragam dan tidak terlalu cerah.

Kata kunci: LAI, biomasa, kamera berlensa mata ikan, persamaan alometrik, Kalimantan Timur

UDC/ODC 630*182.21

Ishak Yassir and Peter Buurman

SOIL ORGANIC MATTER DYNAMICS UPON SECONDARY SUCCESSION IN IMPERATA GRASSLAND, EAST KALIMANTAN, INDONESIA

(PERUBAHAN BAHAN ORGANIK TANAH PADA PROSES SUKSESI SEKUNDER PADA LAHAN ALANG-ALANG DI KALIMANTAN TIMUR, INDONESIA)

Perubahan bahan organik tanah pada proses suksesi di lahan alang-alang telah dipelajari dengan analisis isotop karbon. Data sampel tanah dan serasah dari dua puluh petak contoh dari empat tahapan proses suksesi yang berbeda dibandingkan. Tahapan dari proses suksesi tersebut diwakili oleh petak contoh yang terdiri dari: (1) 3 tahun setelah terbakar (kondisi alang-alang), (2) 9 tahun setelah terbakar, (3) hutan sekunder (≥ 15 tahun) dan (4) hutan primer. Hasil pencermatan menunjukkan menunjukkan bahwa isotop karbon dari semua horizon tanah pada setiap tahapan regenerasi, secara statistik berbeda dengan isotop karbon dari hutan primer. Di Horizon-A pada petak contoh 3 tahun setelah terbakar masih berisi karbon C3 23%, dan fraksi ini meningkat menjadi 51% di horizon-B. Di petak contoh 9 tahun setelah terbakar dan di hutan sekunder, karbon C3 di horizon-A meningkat masing-masing menjadi 51% dan 96%. Di lapisan atas tanah (topsoil), hilangnya karbon C4 antara petak contoh 3 dan 9 tahun terjadi secara signifikan, akan tetapi tidak di horizon-AB. Pembusukan yang terjadi sangat cepat di lapisan tanah pada lahan alang-alang, kemungkinan disebabkan kandungan karbohidrat yang cukup tinggi dari bahan organik, yang dianggap mudah terurai. Penelitian lebih lanjut diperlukan terutama untuk menggali hubungan antara stok karbon dan komposisi kimia bahan organik tanah. Pengetahuan tersebut diharapkan dapat lebih membantu untuk memahami dan memprediksi perubahan karbon tanah dalam kaitannya dengan perubahan iklim dan vegetasi.

Kata kunci: Isotop karbon, lahan alang-alang, suksesi, bahan organik tanah

UDC/ODC 630*111.83:116

Gamma N.M. Sularso, Rudy P. Tambunan, Andreo W. Atmoko

LOW CARBON DEVELOPMENT STRATEGY FOR LAND USE SECTOR IN CILIWUNG MIDDLE-STREAM WATERSHED

(STRATEGI PEMBANGUNAN RENDAH KARBON UNTUK PENGGUNAAN LAHAN DI DAS CILIWUNG BAGIAN TENGAH)

Segmen kedua dan ketiga yang merupakan bagian dari DAS Ciliwung bagian tengah mengalami perubahan penggunaan lahan yang cukup pesat selama dua dekade terakhir. Studi ini dilakukan untuk menganalisis tren perubahan penggunaan lahan pada 1989-2012 dan dampaknya terhadap penurunan stok karbon atau peningkatan emisi CO_2-eq serta proyeksi *Reference Level* (RL) pada tahun 2020. *Reference Level* terbaik digunakan untuk membangun Strategi Pembangunan Rendah Karbon (*Low Carbon Development Strategy*-LCDS) di kedua segmen. Perubahan penggunaan lahan pada 1989-2012 memperlihatkan bahwa terjadi penurunan luasan ruang terbuka hijau (RTH) hingga 3.623,17 ha sedangkan non-RTH meningkat hingga 2.575,57 ha. Hal ini berdampak pada menurunnya stok karbon hingga 26.900 ton C dan melepaskan emisi CO_2-eq hingga 98.723 ton CO_2-eq. Penyebab perubahan penggunaan lahan yaitu pertambahan penduduk, kebutuhan lahan, dan keterbatasan lahan. Proyeksi RL hingga tahun 2020 dilakukan berdasarkan kondisi standar (BAU) dan rencana ke depan (FL). Hasil proyeksi memperlihatkan bahwa FL adalah skenario terbaik yang diestimasi menyimpan karbon hingga 217.610 ton C di tahun 2020. Strategi pembangunan rendah emisi karbon diarahkan pada penambahan luasan RTH hingga 20% melalui implementasi strategi didasarkan pada RTH dan non-RTH meliputi strategi perlindungan, pemantauan, penyuluhan, dan penegakan hukum.

Kata kunci: Stok karbon, reference level, perubahan penggunaan lahan, daerah aliran sungai, Ciliwung

ANALYSIS OF CHEMICAL COMPOUNDS DISTINGUISHER FOR AGARWOOD QUALITIES

Gunawan Pasaribu*, Totok K.Waluyo and Gustan Pari

Forestry Engineering and Forest Products Processing Research and Development Center, Jl. Gunung Batu No. 5 Bogor 16610, Indonesia

Received: 23 October 2013, Revised: 14 October 2014, Accepted: 16 October 2014

ANALYSIS OF CHEMICAL COMPOUNDS DISTINGUISHER FOR AGARWOOD QUALITIES. Gaharu (Agarwood) is described as a fragrant-smelling wood that is usually derived from the trunk of the genus Aquilaria and Gyrinops (both of the family Thymelaeaceae), which have been infected by a particular disease. Based on Indonesian National Standard, agarwood can be classified into various grades, i.e. *gubal gaharu*, *kemedangan* and *serbuk gaharu*. The grading system is based on the color, weight and odor. It seems that such a grading is too subjective for agarwood classification. Therefore, to minimize the subjectivity, more objective agarwood grading is required, which incorporates its chemical composition and resin content. This research was conducted focusing on the analysis of the particular grade of agarwood originating from West Sumatra. The different types of agarwood qualities are: *kemedangan C*, t*eri C*, *kacangan C* and s*uper AB*. Initially, the obtained agarwood samples were grounded to powder, extracted on a Soxhlet extractor using various organic solvents (i.e. n-hexane, acetone, and methanol). The agarwood-acetone extracts were analyzed using GC-MS to determine its chemical composition. The results showed a positive, linier relationship in which the resin yield increased with the increase in agarwood quality grades. GC-MS analysis revealed that several sesquiterpene groups can be found in *kemedangan C*, *teri C*, *kacangan C* and *super AB* qualities. It is interesting that aromadendrene could be identified or found in all agarwood quality grades. Therefore, it is presumed that the aromadendrene compounds can act as an effective chemical distinguisher for agarwood, whereby the greater the aromadendrene content, the better is the agarwood grade.

Keywords: Agarwood, extraction, resin yield, chemical component, gaharu qualities

ANALISIS SENYAWA KIMIA PENANDA KUALITAS GAHARU. Gaharu merupakan produk kayu penghasil resin beraroma wangi dari kayu genus Aquilaria dan Gyrinops (Famili: Thymelaeaceae). Pembentukan gaharu merupakan mekanisme pertahanan pohon terhadap suatu gangguan lingkungan atau penyakit. Berdasarkan Standar Nasional Indonesia, gaharu dapat diklasifikasikan menjadi beberapa tingkatan antara lain gubal gaharu, kemedangan, dan serbuk gaharu. Sistem pengkelasan yang ada didasarkan pada warna, berat, dan aroma. Hal ini menunjukkan bahwa sistem pengkelasan kualitas gaharu saat ini masih subyektif. Oleh karena itu dibutuhkan pengkelasan yang lebih obyektif yang berhubungan dengan komposisi kimia dan kadar resin. Tulisan ini menganalisa kualitas gaharu yang berasal dari Provinsi Sumatera Barat meliputi kemedangan C, teri C, kacangan C, dan super AB. Penelitian dimulai dengan pembuatan serbuk gaharu, kemudian diekstraksi dengan teknik soxhlet menggunakan beberapa pelarut organik (n-heksana, aseton, dan methanol). Ekstrak aseton gaharu dianalisa menggunakan GC-MS untuk menentukan komposisi kimia. Hasil penelitian menunjukkan hubungan linear antara peningkatan kadar resin dengan peningkatan kualitas gaharu. Hasil pengujian GC-MS menunjukkan adanya kelompok sesquiterpena pada gaharu kualitas kemedangan C, teri C, kacangan C, dan super AB. Keberadaan senyawa aromadendrene dijumpai pada semua kualitas gaharu; senyawa ini diduga kuat berperan sebagai senyawa kimia penanda gaharu. Semakin tinggi kadar aromadendrene, kualitas gaharunya semakin baik.

Kata kunci: Gaharu, ekstraksi, kadar resin, komponen kimia, kualitas gaharu

* Corresponding author: gun_pa1000@yahoo.com

I. INTRODUCTION

Agarwood plant consists of Thymelaeaceae, Leguminosae, and Euphorbiaceae families. The Thymelaeaceae has two genera that is categorized by producing high quality agarwood, i.e. *Aquilaria* and *Gyrinops genera* (Sidiyasa & Suharti, 1986; Sumarna, 2002). The species are *Aquilaria malaccensis*, *A. microcarpa*, *A. filaria*, *A. beccariana* and *A. Gyrinops versteegii*. Agarwood is one of the non timber forest products (NTFPs) commodities in Indonesia, which has a high economic value.

The quality of agarwood is determined by its resin content. The higher resin content, the higher class (Mashur, 2009). In general, agarwood is clasified into three groups, i.e. *gubal*, *kemedangan* and *abu* (Mashur, 2009; Salampessy, 2009; Santosa, 2009). The gubal quality consists of double super, *super* A, *super* B, *kacang teri* A, *kacang teri* B and *sabah tenggelam*. The *kemedangan* group consists of *kemedangan* quality A to C, BC quality, kemedang putih and *teri* terapung. The abu group is originating from the cleaning process of the *gubal* and *kemedangan* quality. It is divided into four qualities, i.e *abu gaharu* super, *abu gaharu kemedangan* A, abu gaharu kemedangan and TGC (Mashur, 2009; Salampessy, 2009; Santosa, 2009).

Yoneda et al. (1984) identified the sesquiterpenoids in *Aquilaria agallocha* and *Aquilaria malaccensis* using combination of GLC and GC/MS. The sesquiterpenoids are: β-agarofuran, α-agarofuran, nor-ketoagarofuran, (-)-lO-epi-y-eudesmol, agarospirol, jinkohol, jinkoh-eremol, kusunol, dihydrokaranone, karanone, jinkohol II and oxo-agarospirol. Identification of sesquiterpene compounds in the four grades of agarwood have been done on *Kacangan* B, *teri* B, *kemedangan* A and *kamedangan* B quality. The presence of sesquiterpene and chromone with particular portion and characteristics in each of those four agarwood grades have their roles in explaining their grades from the best to the lowest (Waluyo & Anwar, 2012). Furthermore, Pasaribu, Waluyo and Pari (2013) mentioned that the extracts yield of various solvent of agarwood is decreasing from super AB toward *kacangan* C, *teri* C and *kemedangan* C. The agarwood samples contain furan compounds and ester aromatic groups that is responsible for the agarwood's nice scent.

Balfas (2009) studied the resin content of low-grade agarwood. Raw ma*teri*als of similar grades were collected from Irian Jaya, Jambi (Sumatra) and Banjarmasin (Kalimantan). Extraction results were significantly influenced by the source of the wood samples and the kind of solvent. The use of ethanol gave greater resin yields than the use of methanol or distilled water. However, the use of methanol instead of ethanol is more recommendable for future works.

Determination of agarwood class is related to its price. Based on Indonesian National Standard (SNI, 2011), agarwood can be classified into various grades, i.e. gubal gaharu, kemedangan and serbuk gaharu. The grading system is made according to the color, weight and odor. It seems that such grading is too subjective for agarwood classification. Therefore, to minimize the subjectivity, it is required that more objective agarwood grading is being introduced, such as incorporating the chemical composition and resin content of agarwood.

II. MATERIAL AND METHOD

A. Plant Materials

The material used in this study is natural agarwood (*Aquilaria malaccensis*) which was collected from West Sumatra. Samples were obtained from traders. Agarwood class consisted of *kemedangan C*, *teri C*, *kacangan C* and *super AB*. The chemicals used were methanol, acetone and n-hexane.

B. Extraction

The first step, the obtained agarwood samples were grounded to wood powder, to obtain sizes of 40 to 60 mesh. Then, the wood powder was extracted in soxhlet apparatus using, extracted on a soxhlet apparatus using various organic solvents (i.e. n-hexane, acetone and methanol). Extraction process was done during 3 hours or until the extract in a soxhlet became colorless. The apparatus was heated in water bath with temperature ± 100°C. The extraction was further concentrated by rotary vacuum evaporator. Concentrated extract was agarwood resin, which was blackish brown. Concentrated extracts were then weighted to determine the yield of the agarwood resin.

Extract yield was calculated by formula:

$$\text{Yield (\%)} = \frac{A}{B} \times 100$$

where :
A = resin weight after extraction
B = powder weight before extraction

C. Chemical Compound Analysis

Acetone extracts of agarwood qualities i.e. *kemedangan C*, *teri C*, *kacangan C* and super AB were used for the analysis. The analysis used Gas Chromatography Mass Spectra (GCMS) at Forensic Laboratory Center (Puslabfor POLRI), Indonesian Police Headquarters. The GCMS specification is electron ionization detector attack (EI) on GC-17A gas chromatograph (Shimadzu) which combined with MS QP 5050A mass spectrometer, and with the Wiley 7N 2008 data base. GC/MS instrument (Shimadzu QP 2010) running time was 39.67 minutes, with the initial GC oven temperature of 70°C, and final temperature of 290°C, using DB5 MS detector.

III. RESULT AND DISCUSSION

A. General Condition

The specific site of agarwood source is Nagari Lubuk Basung, Sub-district Lubuk Basung, West Sumatra Province. The collection of natural agarwood has decreased because of the limited availability in the forest. Some people have started to cultivate the agarwood. The other Nagari (village) who is looking for agarwood is the Batu Kambing and Nagari Sitanang villages, sub-district Ampe Nagari, district Agam. One of the businessmen in agarwood (Hasan Basri) told about the existing agarwood business specifically in West Sumatra and the island of Sumatra in general.

He has started agarwood business 20 years ago. His target market is the Middle East by going directly to the buyers in Kuwait, Bahrain, Qatar and Saudi Arabia. In the Middle East, the most favorite agarwood species is *Aquilaria malaccensis*. In West Sumatra, agarwood comes from Mentawai, Agam, Pasaman and Pesisir Selatan districts. According to his experience, agarwood is used by people in the Middle East for relaxation and stamina (sexuality).

The grading classification used in West Sumatra is different from the Indonesian National Standard (SNI). The trader's classificaton is ranging from double Super, Super A, Super B, Super AB, Super BC, *Kacangan*, *Teri* (three levels) to *kemedangan* (three levels). Some level classes and prices are presented in Table 1. The collector in Nagari usually sells

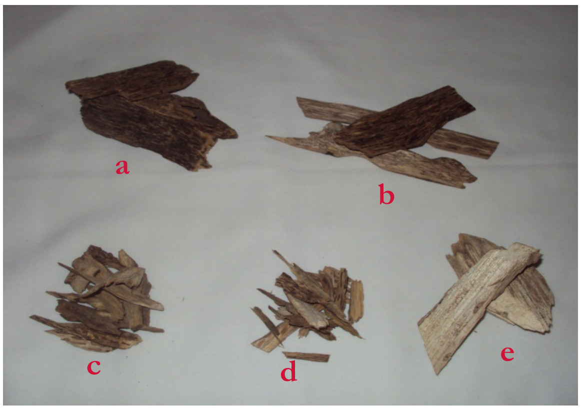

Figure 1. Some of agarwood grades from West Sumatra
Remarks: a. *Super AB*, b. *Super BC*, c. *Kacangan C*, d. *Teri C*, e. *Kemedangan C*

Table 1. The prices of some of agarwood qualities in West Sumatra

No	Quality class	Price (IDR) / kg
1.	*Super AB*	8,750,000 - 10,000,000
2.	*Super BC*	1,500,000 - 2,000,000
3.	*Kacangan*	1,100,000 - 1,500,000
4.	*Teri*	350,000 - 500,000
5.	*Kemedangan bagus*	300,000 - 400,000
6.	*Kemedangan biasa*	75,000 - 150,000

directly to the province collectors. Further, the businessman in the province is selling to a big businesman or exports directly to the Middle East.

B. Extraction and Yield

The Soxhlet extraction results of various solvents from West Sumatra are presented in Table 2. The use of Soxhlet extraction is proper for compounds that are not affected by heat, and also it is more economical.

The methanol resin yield was higher than acetone and n-hexane yields. The study of Pasaribu et al. (2013) showed differences in the yield of the extract of agarwood with methanol, acetone and hexane solvent. Balfas (2009) said that the use of ethanol gave greater yields of resin than the use of methanol or distilled water.

There was no difference in the yield of resin between methanol and acetone solvents, but by using methanol solvent the yield tended to increase. In case of aceton extract of Super AB, the yield looks higher than methanol extract. The methanol solvent has a property that can dissolve almost all of the components in polar, semi-polar and non-polar solvent.

The agarwood resin yield indicates generally that the super AB has the highest level in resin level, followed by *kacangan* C, t*eri* C and *kemedangan* C. In general, the higher quality of agarwood, the higher is the resin yield. The consistency of the resin content can be used as a valid measure to classify agarwood grade.

C. Chemical Component Analysis

The results of the analysis of chemical components of four agarwood resin grades from West Sumatra are presented in Table 3. Extracts analyzed were from acetone extracts; based on the literature which suggested that sesquiterpene compound isolation is better than using acetone solvent. The acetone solvent is better to dissolve the resin which is an agarwood extract as resinous product. Ishara, Tsuneya and Uneyama (1993) used acetone solvent to extract sesquiterpene compound from *Aquilaria agallocha* agarwood. In order to isolate resin from rubber wood acetone solvent was also used that has a good property in isolating resin groups (American Society for Testing and Materials [ASTM], 1997). Agarwood as resinous group is more suitable to be extracted by semi-polar solvent. The *Like Dissolve Like Theory* explains that solvents will dissolve the compounds according to their solubility properties. The polar solvents will dissolve polar compounds easier and non-polar solvents will be easier to dissolve by non-polar compounds (Harborne, 1987). Chemical components with high percentage peaks at retention time, namely 7.57, 8.76, 8.9, 9.0 and 10.6 are not included in sesquiterpene compounds groups. The compounds are 2,5-bis(2,2-dimethylpropylidene) cyclopentanone; beta.-Maaliene; Naphthalene, decahydro-4a-methyl-1-methylene-7-(1-methylethylidene)-, (4aR-trans)-; Tricyclo[3.2.1.02,7]oct-3-ene, 2,3,4,5-tetramethyl-; and valerenol. This compounds group is commonly found in healthy

Table 2. Agarwood resin yield

No	Quality	Moisture content (%)	Yield (%)		
			Methanol	Acetone	n-hexane
1.	*Kemedangan C*	7.39	9.53	9.07	4.57
2.	*Teri C*	11.48	20.91	19.25	1.42
3.	*Kacangan C*	10.30	24.95	21.04	0.81
4.	*Super AB*	8.11	27.34	30.71	3.50

agarwood (not infected) (Chen, Yeh, Chao, & Chen, 2013). The GCMS chromatogram of *super* AB is presented in Figure 2.

The results of testing the chemical composition refers to the chemical composition of agarwood reviewed by Chen et al. 2013. From Table 3 it can be explained that the aromadendrene compound group (Figure 3) is present in all grade tested. Aromadendrene is one of the sesquiterpene derivatives. It was presumed that its compound is one of the distinguisher compound (chemical marker) of agarwood. The increasing aromadendrene chemical content indicated increasing agarwood level. On the other hand, this research showed that there are some sesquiterpenene chemical compound with the same compound was isolated before by Yoneda et al. (1984). For example the β-agarofuran and α-agarofuran compounds.

However, Waluyo and Anwar (2012) research showed that there is no consistency in sesquiterpene compounds type for each quality of agarwood. The chromone and sesquiterpene compounds are found in kacangan B, teri B, kemedangan A and kemedangan B qualities. Likewise Pasaribu et al. (2013), stated that agarwood grade (super AB, kacangan C, teri C, and kemedangan C) showed that the agarwood contain furan compounds and ester aromatic groups that are responsible for agarwood's nice scent. There are many causes which can make the differences in the results of agarwood resin spectroscopy. The causes can be the type of

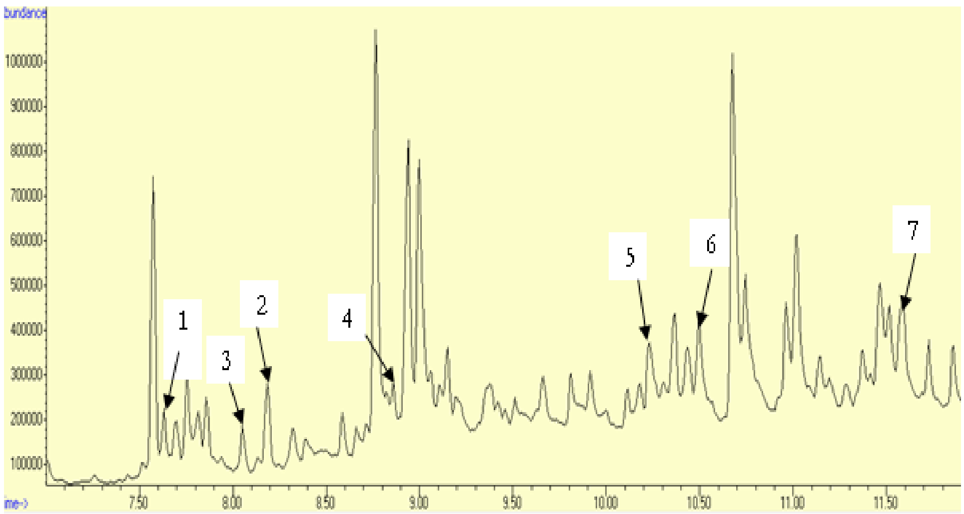

Figure 2. GCMS chromatogram of Super AB extract

Remarks:1. β-agarofuran, 2. α-agarofuran, 3. α-gurjunene, 4. Agarospirol, 5. Chromone, 6. Aromadendrene epoxide, 7. Aromadendrene

Table 3. Chemical components of agarwood

No	Quality	Chemical component	%
1.	*Kemedangan C*	Alloaromadendrene	0.77
2.	*Teri C*	Aromadendrene	0.66
		Aromadendrene epoxide	0.77
		Isoaromadendrene epoxide	2.10
		Alloaromadendrene	0.81
3.	*Kacangan C*	β-agarofuran	0.47
		α-gurjunene	0.20
		Agarospirol	0.67
		Aromadendrene	1.65
		Isoaromadendrene epoxide	0.53
4.	*Super AB*	Aromadendrene	2.57
		β-agarofuran	0.74
		α-gurjunene	0.46
		α-agarofuran	0.77
		Agarospirol	0.74
		Chromone	1.58
		Aromadendrene epoxide	1.55

raw material, the source of raw material of the different species.

Similarly, the different locations of plant growing of the same species can produce different chemical content. The method of analysis can also produce different outputs of the chemical content, due to differences in the condition of GCMS column and databases used in the tool. Nakanishi et al. (1984) said that the main fragrant compounds of agarwood are sesquiterpenes and phenylethyl chromone derivatives, and a great variety of sesquiterpenes are contained in high-level agarwood.

IV. CONCLUSION

The agarwood resin yield is influenced by the quality of the agarwood. A positive linier relationship has been found in which the resin yield increased with the increase in agarwood class grades.

The aromadendrene compound could be identified or found in all agarwood quality grades. Therefore, it is presumed that the aromadendrene compounds can act as an effective chemical distinguisher (chemical markers) for agarwood, whereby the greater the aromadendrene contents the better the agarwood grade.

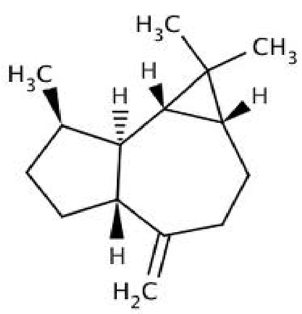

Figure 3. Aromadendrene structure

ACKNOWLEDGEMENT

The authors are very grateful to the Center for Forest Product Research and Development for financial support to conduct this research. Thanks also due to Pudji Hastuti and Umi Kulsum for their help on the laboratorium.

REFERENCES

American Society for Testing and Materials (ASTM). (1997). ASTM-D 297-93: Standard test methods for rubber products - Chemical analysis. West Conshohocken, USA: American Society for Testing of Materials.

Badan Standardisasi Nasional. (2011). Agarwood Indonesian National Standard *SNI 7631:2011 (SNI.01-5009.1-1999)* (in Bahasa Indonesia). Indonesia: Badan Standardisasi Nasional.

Balfas, J. (2009). Resin content on the low-grade agarwood. *Journal of Forest Product Research*, *27* (2), 97–105.

Burfield, T. (2005). Agarwood chemistry. Retrieved August 03, 2009, from http://www.cropwat.org/Agarchem.html.

Chen, C.T., Yeh, Y.T., Chao, D., & Chen, C.Y. (2013). Chemical constituent from the wood of Aquilaria sinensis. *Chemistry of Natural Compounds*, *49*(1), 113–114.

Chen, H.Q., Wei, J.H., Yang, J.L., Ziang, Z., Yang, Y., Gao, J.-H. Gong, B. (2012). Review : Chemical constituens of agarwood originating from the endemic genus Aquilaria plants. *Chemistry and Biodiversity*, *9*, 236–250.

Harborne, J.B. (1987). Phytochemical methods*: A Guide to Modern Techniques of Plant Analysis* (2nd Ed.) (in Bahasa Indonesia). Bandung: ITB.

Ishara, M., Tsuneya, T., & Uneyama, K. (1993). Fragrant sesquiterpenes from agarwood. *Phytochemistry*, *33*(5), 1147–1155.

Mashur. (2009). Market opportunities of cultivated agarwood (in Bahasa Indonesia). Paper presented at The 1st National Seminar of Agarwood, Bogor 12 November 2009.

Nakanishi, T., Yamagata, E., Yoneda, K., Nagashima, T., Kawasaki, I., Yoshida, T., Miura, I. (1984). Three fragrant sesquiterpenes of agarwood. *Phytochemistry*, *23*, 2066–2067.

Pasaribu, G., Waluyo, T.K., & Pari, G. (2013). Analisys of chemical compound in some of agarwood quality by gas chromatography mass spectrometry. *Journal of Forest Product Research*, *31*(3), 181–185.

Salampessy, F. (2009). Strategy and technique marketing of agarwood in Indonesia. Paper presented at Workshop of technology development of agarwood production based on forest communities empowerment, Bogor 29 April 2009 (in Bahasa Indonesia).

Santosa, H. (2009). Conservation and utilization of agarwood. Paper presented at The 1st National Seminar of Agarwood, Bogor 12 November 2009. (in Bahasa Indonesia)

Sidiyasa, K., & Suharti, M. (1986). *Types of plants producing agarwood* (in Bahasa Indonesia). Paper presented at Discussion of lesser known timber trees utilization at Bogor in 1996.

Sumarna, Y. (2002). Cultivation and Production engineering of tree species producing agarwood (in Bahasa Indonesia). Paper presented at Sosialisasi Gaharu di Gorontalo.

Waluyo, T.K., & Anwar, F. (2012). Chemical component identification of four agarwood grades: Kacangan A. Teri B. Kamedangan A and Kamedangan B. *Journal of Forest Product Research*, *30*(4), 291–300.

Yoneda, K., Yamagata, E., Nakanishi, T., Nagashima, T., Kawasaki, I., Yoshida, T., … Miura, I. (1984). Sesquiterpenoids in two different kinds of agarwood. *Phytochemistry*, *23*(21), 2068–2069.

Indonesian Journal of Forestry Research Vol. 2, No. 1, April 2015, 9-20 ISSN: 2355-7079 / E-ISSN: 2406-8195

PHOTOSYNTHETIC RESPONSES OF *Eucalyptus nitens* AT INITIAL STAGES OF ROOT-ROT INFECTION

Luciasih Agustini[1,*], Chris Beadle[2], Karen Barry[3] and Caroline Mohammed[2,3]

[1]Research and Development Center for Forest Conservation and Rehabilitation, Jl. Gunung Batu No. 5 Bogor 16610, Indonesia
[2]CSIRO Ecosystem Sciences, Private Bag 12, Hobart, Australia
[3]Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 98, Hobart, Australia

Received: 28 November 2013, Revised: 31 October 2014, Accepted: 2 November 2014

PHOTOSYNTHETIC RESPONSES OF *Eucalyptus nitens* AT INITIAL STAGES OF ROOT-ROT INFECTION. Root-rots are known to be latent diseases that may be present in plants for an extended period without any noticeable expression of symptoms above ground. Photosynthetic responses of *Eucalyptus nitens* saplings artificially inoculated with the root-rot pathogen, *Armillaria luteobubalina* were examined to characterize the initial stages of root-rot infection. This paper studies three photosynthetic parameters, i.e. photosystem II yield (F_v/F_m), chlorophyll content and photosynthetic capacity (A_{max}) for two strains of *A. luteobubalina* over a seven-month period. Root systems were either wounded or left intact before inoculation. A significant difference was observed in the F_v/F_m ratio between the uninoculated control and inoculated saplings. Photosystem II yield was considered the most sensitive parameter for the early detection of root-rot disease. Chlorophyll content and A_{max} decreased for all trees, including controls, during the period of the experiment, and most likely reflected host responses to seasonal change rather than treatment effects. Fungal re-isolations from symptomatic roots of inoculated trees confirmed the presence of *A. luteobubalina*. Findings from this preliminary trial indicated that there were detectable physiological changes associated with early infection of root-rot. However, to detect more widespread physiological changes an experiment of longer duration is needed.

Keywords: *Eucalyptus nitens*, artificial inoculation, chlorophyll content, photosynthetic rate, photosystem II yield, root disease

RESPON FOTOSINTESIS Eucalyptus nitens *PADA TAHAP AWAL INFEKSI PENYAKIT BUSUK AKAR. Penyakit busuk akar merupakan penyakit yang bersifat laten yang dapat menginfeksi tanaman dalam jangka waktu lama tanpa menimbulkan gejala yang dapat diamati. Oleh karena itu, untuk mengetahui karakter perubahan fisiologis sebelum timbulnya gejala, telah dilakukan percobaan mengenai respon fotosintesis tanaman pada tahap awal infeksi penyakit busuk akar dengan cara menginokulasi anakan pohon* Eucalyptus nitens *dengan pathogen* Armillaria luteobubalina. *Inokulasi buatan dilakukan dengan menggunakan dua strain* A. luteobubalina *dan dua variasi perlakuan akar, yaitu : dilukai dan tidak dilukai. Respons fotosintesis diamati dengan cara mengukur tiga parameter fotosintesis, yaitu: efisiensi fotosistem II (Fv/Fm), kadar klorofil dan laju fotosintesis (*A_{max}*). Pengamatan dilakukan selama tujuh bulan. Perbedaan yang signifikan ditunjukkan oleh data efisiensi fotosistem II (rasio Fv/Fm) antara kontrol dengan perlakuan-perlakuan lainnya. Fv/Fm merupakan parameter yang paling sensitif untuk mengindikasikan serangan awal penyakit busuk akar. Adapun parameter kadar klorofil dan laju fotosintesis (*A_{max}*) menunjukkan nilai yang menurun baik pada tanaman kontrol maupun perlakuan. Perubahan nilai kedua parameter fotosintesis tersebut lebih ditentukan oleh perbedaan musim. Patogen* A. luteobubalina *berhasil diisolasi kembali dari akar* E. nitens *yang menunjukkan penurunan respons fotosintesis. Hal tersebut menunjukkan bahwa penurunan respon fotosintesis berkaitan dengan adanya infeksi awal penyakit busuk akar. Namun diperlukan percobaan dengan waktu pengamatan yang lebih lama, agar perubahan respon fisiologis lainnya dapat terdeteksi.*

Kata kunci: Eucalyptus nitens, inokulasi buatan, kadar klorofil, laju fotosintesis, efisiensi fotosistem II, busuk akar

[*]Corresponding author: luci_agustini@forda-mof.org; luciagustini@yahoo.com

I. INTRODUCTION

Root-rots significantly reduce the productivity of important crops in tropical countries. For the majority of pathogens causing root-rot diseases, there is no clear indication of early infection (Mohammed, Rimbawanto & Page, 2014). As such, methods for early detection of root-rot disease are important for the pulp, oil palm and rubber industries. Early detection might allow the implementation of effective remedial measures to combat root-rot diseases as long as associated costs are not prohibitive e.g. the removal of infected woody material and/or the targeted application of biocontrol agents in the area infected. However, early detection is difficult because individual trees can appear healthy above ground even when damage to the root system has become severe (Hadfield, Goheen, Filip, Schmitt & Harvey, 1986; Farid, Lee, Maziah, Rosli & Norwati, 2006). For example, in the case of basal stem rot in oil palm, foliar symptoms are only visually observed when the fungus has killed half of the basal stem (Mohammed et al., 2014).

Observation of thin crowns, growth reduction and/or foliage chlorosis have proven to be useful indicators for detecting infected tree for many root-rot diseases (Morrison, Williams & Whitney, 1991; Omdal, Shaw & Jacobi, 2004). At the leaf scale, root-rot diseases can induce many changes to the biochemical, physiological and structural properties of leaves, which may result in a range of visual symptoms including needle chlorosis, production of non-green metabolites, necrosis and desiccation. These changes can potentially be used for monitoring the health and condition of forests (Stone, Coops & Culvenor, 2000, Luyssaert, Raitio, Vervaeke, Mertens & Lust, 2002; Gunthardt-Goerg & Vollenweider, 2007). For example, chlorophyll content has often been advocated as a sensitive indicator of many types of plant stress including drought, nutrient deficiency and diseases (Barry, Stone & Mohammed, 2008). Determining leaf-level physiological responses of the host plants during the initial stage of root-rot infection could provide valuable information that may help with developing methods for the early detection of root-rot. To date, there has been little research on the effect of root disease on the host's physiology before the appearance of visual symptoms.

Photosynthetic capacity is useful parameter for monitoring these physiological changes. Stressful agents including fungal diseases can reduce the photosynthetic capacity due to their influence on one or more of the partial processes associated with photosynthesis (Dubey, 1997; Pinkard & Mohammed, 2006). This influence may include decreased light-energy utilization, decreased chlorophyll content, the destruction of the chloroplast fine structure, degradation of photosystem (PS) II and alteration of biochemical processes (Sharma & Hall, 1992; Sigh & Dubey, 1995; Dubey, 1997; Chou, Bundock, Rolfe & Scholes, 2000; Lopes & Berger, 2001; Meyer, Saccardt, Rizza & Genty, 2001; Berger, Papadopoulos, Schreiber, Kaiser & Roitsch, 2004; Robert, Bancal, Nicolas & Lannou, 2004; Berger, Sinha & Roitsch, 2007).

The degree of inhibition of photosynthesis may be indicative of the aggressiveness of the pathogen (Guest & Brown, 1997). Root pathogens, such as species of *Armillaria*, which occupy and alter the host's vascular tissue (Morrison et al., 1991) may influence the photosynthetic activity indirectly by affecting the pathways of water flow in the xylem. The impact of root-rot on photosynthetic activities may be similar to the disruptions caused by water stress that is associated with decreased stomatal conductance, a lowering of intercellular CO_2, decreased chlorophyll level, changes in ultra-structure of chloroplasts, alteration in electron transport and decreased activity of the enzyme ribulose biphosphate carboxylase (Dubey, 1997).

Physiological aspects of plant-pathogen interactions have been well studied, especially for foliar diseases (Goicoechea, Aguirreolea, Cenoz & Garcia-Mina, 2001; Bonfig, Schreiber, Gabler, Roitsch & Berger, 2006; Pinkard & Mohammed, 2006; Rodriguez-Moreno et al., 2007). In contrast, understanding the effects of root-rot diseases on plant physiology, especially in relation to hardwood trees, has received little attention. This paper observes physiological changes before the appearance of root-rot's visual symptoms.

We used the *Eucalyptus nitens* (H. Deane and Maiden) Maiden and *Armillaria luteobubalina* Watling and Kile model pathosystem to quantify the photosynthetic changes of the host plant in response to root-rot disease. *Armillaria luteobubalina* is a generalist pathogen that has approximately 88 hosts (Shaw & Kile, 1991). This fungal species has been observed to cause root-rot in 3-year- and 6-year-old *E.nitens* plantations in Tasmania, Australia (Tim Wardlaw, personal communication). Findings from this pathosystem model will contribute valuable information about the potential to develop an early detection method of root diseases that are currently threatening the productivity of tropical plantation crops such as hardwoods, rubber and oil palm. In this experiment, the hypothesis that root infection will alter the processes associated with photosynthesis before the visual appearance of the disease symptoms is tested. We undertook a pot trial to characterize early physiological responses, (1) photosynthetic efficiency or photosystem (PS) II yield (F_v/F_m via chlorophyll fluorescence), (2) chlorophyll content, and (3) photosynthetic rate (A_{max}) of *E. nitens* saplings to artificial inoculation with *A. luteobubalina*. Re-isolation of *A. luteobubalina* from symptomatic trees was also conducted in order to confirm whether the measured physiological changes were associated with the fungal pathogen infection.

II. MATERIAL AND METHOD

A. Plants and Isolates

Forty-two two-year-old *E. nitens* saplings were planted in 30-cm-diameter pots containing a potting-mix medium consisting of soil, sand, and pine-bark compost (1:1:1). A previous pilot study showed that this mixed-soil medium was suitable for maintaining the viability of the inoculum. The saplings were fertilised with 15g of a slow-release fertilizer (Osmocote®) and watered daily with drippers until saturated.

The fungal cultures were obtained by isolating from infected roots of an ornamental olive tree in the Hobart Royal Botanical Gardens, Australia (isolate strain 1) and a *Cupressus* sp. in Cascade Brewery Garden, Australia (isolate strain 2). Molecular analysis identified both isolates as *A. luteobubalina* having 98-100% sequence similarity with the described isolates in GenBank; there was a difference of seven nucleotides between isolates strains 1 and 2 (Agustini, 2010).

B. Fungal Isolations

Pure cultures of *A. luteobubalina* isolate strains 1 and 2 were obtained from sterilized infected root samples grown on 1% malt extract medium with the addition of selected antibiotics (MAT). Specifically, the MAT medium was prepared by autoclaving 1% malt extract agar (MEA) for 30 min at 120°C. Antibiotics (50 ppm penicillin, 50 ppm streptomycin, 25 ppm polymixin and 230 ppm thiabendazole) were added to the autoclaved MEA during cooling (i.e. at < 60°C). Root samples were surface-sterilised through a series of washings in different solutions, i.e.2 min in tap water, 2-3 min in 20% Chlorox™ (sodium hypochlorite solution), and three times in sterile water. Hyphae that grew from the root samples were sub-cultured onto 2% MEA and incubated in the dark at 21°C for at least one month.

C. Inoculum Preparation and Artificial Inoculation of Plant Material

Branches harvested from young *Eucalyptus globulus* Labill. were prepared as inoculum rods using the method described by Mansilla et al. (2001), with some modification. The colonisation method involved inserting, under sterile conditions, branch segments (5-6 cm in length and 1-2 cm in diameter) that had been autoclaved for 30 min at 120°C into a 200 mL tissue culture vessel (round autoclavable polycarbonate container with lid). This vessel contained 150 mL of sterile MAT medium. Additional MAT medium was added to ensure that the branch segments were completely submerged in agar. These branch segments were inoculated with *A. luteobubalina* by placing seven

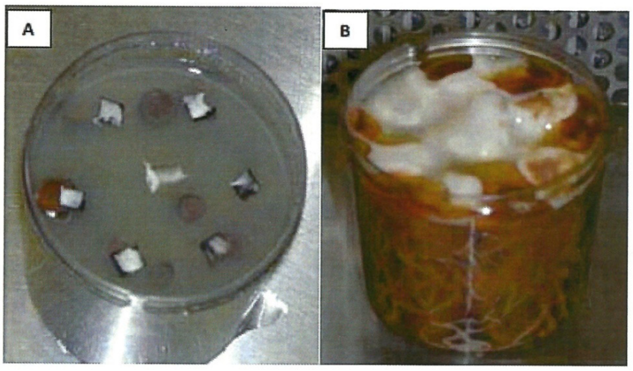

Figure 1. Pieces of agar with mycelia of *A. luteobubalinaon* the MAT media (A), Mycelial fans after incubation at 21°C for three months (B)

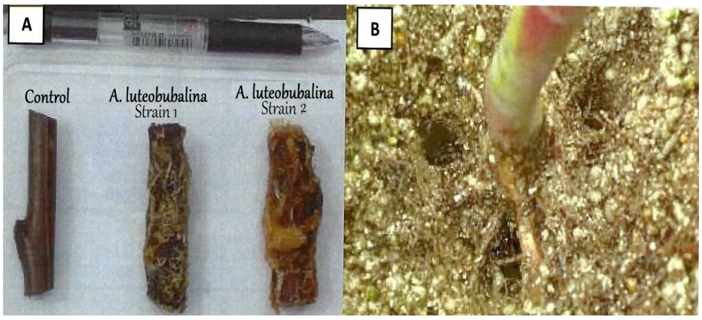

Figure 2. Inoculum rods (A), Inoculation sites: three holes close to the root collar (B)

colonised mycelial segments (approx. 1 cm^2) onto the agar surface (Figure 1A). Each vessel was then closed, sealed with plastic film, and placed in the dark at 21-22°C for approximately three months until the *E. globulus* branches, hereafter referred to as inoculum rods, had been fully colonised with the mycelia and rhizomorphs of *A. luteobubalina* (Figure 1B and 2A). Tissue culture vessels with uninoculated branch segments were also prepared to serve as controls.

Eucalyptus nitens saplings were inoculated by placing fully colonised inoculum rods (Figure 2A) into each pot adjacent to and just touching lateral roots in close proximity to the root collar (Figure 2B). The wounding treatment involved removing a small piece of bark (approx. 0.5-1 cm length) from the lateral roots using a Swiss Army knife.

D. Experimental Layout

A factorial design was applied in this green-house-based experiment. Six treatments were tested, including two physical treatments (*i.e.* unwounded and wounded host-root systems), and two different fungal treatments (*i.e.Armillaria* strain 1 and strain 2) and an uninoculated control. The physical treatments were applied in order to examine the ease of pathogen entry into the root tissue. The six treatments were: unwounded-control (UW-P0), wounded-control (W-P0), unwounded-isolate strain 1 (UW-P1), wounded-isolate strain 1 (W-P1), unwounded-isolate strain 2 (UW-P2), and wounded-isolate strain 2 (W-P2). Each treatment consisted of seven replications, resulting in a total of 42 saplings. The *E. nitens* saplings were arranged in a randomised within the block design.

E. Physiological Measurements

Photosynthetic capacity (A_{max}) and maximum quantum yield of photosystem II yield (F_v/ F_m) were assessed just prior to inoculation (T_0, 2 October 2008; Spring) and after the first symptoms were observed (T2, 29 April 2009; Autumn). During the seven months between T_0 and T_2, an intermediate measurement (T1, 30 January 2009; Summer) of F_v/F_m was carried out to determine if there was any evidence of alterations in the plants' physiology prior to the appearance of the visual symptoms. Measurement frequency was decided based on the preliminary trial results which showed no significant differences in the above physiological variables between control and inoculated saplings over a six-month period. It suggested that extensive monitoring during the first six months after inoculation was not warranted.

Physiological assessments of F_v/F_m, A_{max} and relative chlorophyll content were made on three fully-expanded leaves per sapling. The leaves were selected from the third or fourth leaf pair just behind the branch tip. All plants (42 saplings) were assessed. Chlorophyll fluorescence (F_v/F_m) was measured pre-dawn using a chlorophyll fluorometer (OS-30p Opti-Science). Photosynthetic rate (A_{max}) was quantified using a CIRAS infrared gas analyser (PP Systems, Herts, UK) with an artificial light source set to deliver 1500 µmol m^{-2} s^{-1} at the leaf surface and ambient CO_2 concentration (370 – 380 ppm).

A Minolta SPAD-502 chlorophyll meter (Konica-Minolta, Hong Kong, China) was used to obtain relative chlorophyll content. The SPAD was calibrated by directly measuring the chlorophyll concentration of thirty leaves. Fresh leaf discs (dry weight of each disc~ 0.020 g) were extracted for chlorophyll content with a triple extraction method (Martin et al., 2007). Discs were ground in a mortar with approximately 50 µg M_gCO_3, 50 µg washed, fine sand and a small volume of liquid nitrogen. Ground leaf material was extracted with three small volumes of 100% cold acetone, and centrifuged for 3 min. Absorbance was read at 470, 645, 663 and 710 nm with a Cary UV-VIS spectrophotometer (Varian Medical Systems, Inc., Palo Alto,CA, USA). Total chlorophyll (Chl *a* and *b*) was calculated using the equations of Lichtenthaler and Buschmann (2001). Using this data, a standard curve was created and the SPAD values converted to chlorophyll concentration (µg/g).

F. Fungal Re-isolations

All roots including those from inoculated and control plants were examined at the end of the experiment. Root balls were thoroughly washed and the inoculum rods were removed. Any symptoms and/or signs of infection were recorded and photographs taken. Fungal re-isolations were undertaken from symptomatic roots exhibiting lesions and/or fungal mycelium (Figure 3). This was done to confirm that the causal agent associated with the deterioration of the plants was *A. luteobubalina*. The re-isolations were carried out in the same way as the isolations described above.

Based on the presence or absence of fungal signs and/or root symptoms, four categories were established to describe the infection and root condition:

1. Positive infection by *A. luteobubalina*: as indicated the presence of either mycelial fans and/or lesion with white mycelia (early stage of mycelia fans) on the excavated root; fungal re-isolation was positive for *A. luteobubalina*.
2. Possible infection by *A. luteobubalina*: as indicated by the presence of a smalllesion with white mycelia; fungal re-isolation was negative for *A. luteobubalina*.
3. Infection by un-inoculated fungi: Neither mycelia fans nor white mycelia observed; only necrotic tissue or lesion present; fungal re-isolation confirmed fungi other than *A. luteobubalina*.
4. Uninfected: no fungal signs and/or root symptoms and roots appear healthy.

G. Data Analysis

Two-way analysis of variance (ANOVA) performed in XLSTAT2011® was used to analyse the physiological data. Duncan's multiple range tests were used to determine significant differences among treatments.

III. RESULT AND DISCUSSION

A. Changes in Physiological Variables

Physiological variables measured just before inoculation (T_0)were not significantly different

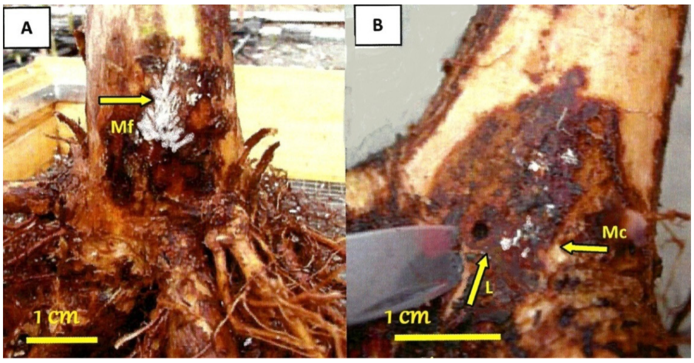

Figure 3. Mycelial fans (Mf) (A), lesion (L) and mycelia (Mc) on the root collar of infected *Eucalyptus nitens* saplings (B)

Table 1. Means ± (SE) of the efficiency of PS II (F_v/F_m), chlorophyll content and photosynthetic rate (A_{max}) of *E. nitens* saplings inoculated with *A. luteobubalina* isolates over the period of observations at T_0, T_1(4 months after T_0) and T_2(7 months after T_0)

Treatments / Time	Physiological variables		
	Efficiency of PS II F_v/F_m	Chlorophyll content µg/g	Photosynthetic rate (A_{max}) µmol/m²/s
UW-P0 / T_0	0.78 ± 0.01 [a]	2918.8 ± 231.1 [a]	12.9 ± 2.2 [a]
W-P0 / T_0	0.77 ± 0.02 [a]	2772.1 ± 168.8 [a]	11.0 ± 0.5 [a]
UW-P1 / T_0	0.79 ± 0.01 [a]	2824.3 ± 110.3 [a]	11.6 ± 1.5 [a]
W-P1 / T_0	0.78 ± 0.01 [a]	2750.1 ± 90.0 [a]	13.5 ± 0.8 [a]
UW-P2 / T_0	0.79 ± 0.01 [a]	2552.3 ± 169.5 [a]	13.0 ± 0.8 [a]
W-P2/ T_0	0.79 ± 0.00 [a]	2918.8 ± 157.4 [a]	13.9 ± 1.1 [a]
UW-P0 / T_1	0.83 ± 0.01 [a]	NA	NA
W-P0 / T_1	0.82 ± 0.00 [a]	NA	NA
UW-P1 / T_1	0.81 ± 0.01 [a]	NA	NA
W-P1 / T_1	0.82 ± 0.00 [a]	NA	NA
UW-P2 / T_1	0.82 ±0.00 [a]	NA	NA
W-P2/ T_1	0.82 ± 0.00 [a]	NA	NA
UW-P0 / T_2	0.81 ± 0.01 [a]	2117.7 ± 119.6 [a]	10.0 ± 0.4 [a]
W-P0 / T_2	0.76 ± 0.01 [b]	1939.0 ± 133.9 [ab]	8.5 ± 0.7[ab]
UW-P1 / T_2	0.74 ± 0.02 [b]	1673.7 ± 119.0 [bc]	8.0 ± 1.0[ab]
W-P1 / T_2	0.75 ± 0.01 [b]	1490.7 ± 81.3 [c]	7.7 ± 0.6[b]
UW-P2 / T_2	0.73 ± 0.01 [b]	1629.1 ± 88.9 [bc]	7.2 ± 1.1[b]
W-P2/ T_2	0.75 ± 0.01 [b]	1715.8 ± 70.5 [bc]	8.4 ± 0.5[ab]

Notes:
- The values followed by different letters in the same column are significant at α=0.05, as determined by a Duncan's test-ANOVA for each variable at each time of observation.
- NA = Not attempted

across treatments (Table 1). Three months after inoculation at intermediate assessment (T_1), photosynthetic efficiency of PS II (F_v/F_m)was unaffected by treatments (Table 1). The first physiological changes were detected seven months after inoculation (T_2) when a significant difference in F_v/F_m between the unwounded controls (UW-P0) and all other treatments

Table 2. Change (± SE) calculated asT_2 -T_0 of physiological variables (F_v/F_m, chlorophyll content and A_{max}) of *E. nitens* saplings inoculated with *A. luteobubalina* isolates.

Treatments	Photosynthetic variables		
	Efficiency of PS II (F_v/F_m)	**Chlorophyll content** (µg/g)	**Photosynthetic rate** (**A_{max}**)µmol/m²/s
UW-P0	0.03 ± *0.01* [a]	-801.1 ± *126.1*[a]	-3.0 ± *1.9*[a]
W-P0	0.00 ± *0.02*[ab]	-833.1 ± *163.6*[a]	-2.5 ± *0.8*[a]
UW-P1	-0.05 ± *0.03*[bc]	-1150.6 ± *107.4*[ab]	-3.7 ± *1.4*[a]
W-P1	-0.03 ± *0.01*[bc]	-1259.4 ± *99.7*[b]	-5.8 ± *0.9*[a]
UW-P2	-0.06 ± *0.02*[c]	-923.2 ± *188.6*[ab]	-5.6 ± *1.5*[a]
W-P2	-0.04 ± *0.01*[bc]	-1116.9 ± *140.6*[ab]	-5.5 ± *1.1*[a]

Note: The values followed by different letter in the same column are significant at α=0.05, as determined by separate Duncan's test-ANOVA for each parameter at each time of observation.

was observed (Table 1). In particular, the F_v/F_m saplings in the unwounded-control (UW-P0) treatment increased, while in the other treatments F_v/F_m decreased; reductions in F_v/F_m were significantly greater in the inoculated (for both isolates and wound types) plants than in the UW-P0 treatment (Table 2).

Treatments effects on chlorophyll content (total Chl a and b) and Amax were more variable. At T2, there was a significant difference in chlorophyll content between inoculated (for both isolates and wound types) and UW-P0 plants (Table 1). Chlorophyll content decreased over the seven-month period of the experiment but, except for UW-P1 plants, there was no differences between inoculated and control treatments (Table 1). Photosynthetic capacity (A_{max}) decreased in all treatments during this period but there were no significant differences between treatments (Table 2).

Statistical tests show that the response of photosynthetic efficiency of PS II was affected by an interaction between time and treatments (F-ratio = 3.798, P-value = 0.005). For chlorophyll content and photosynthetic rate, the responses were more determined by sampling date (P-value <0.0001).

Plant physiological changes associated with root-rot disease are not easy to detect. This is because diseases take time to develop before the plant expresses detectable physiological changes to the pathogen infection (Brown et al., 2012). This study found that *E. nitens* saplings grown under semi-controlled conditions required approximately seven months for developing the first detectable changes in physiological performance following artificial inoculation with *A. luteobubalina* (Table 1).

In this study, F_v/F_m was shown to be the most sensitive physiological variable to detect stress caused by the root-rot pathogen; a significant reduction in F_v/F_m in response to inoculation was observed seven months after treatment. Changes in F_v/F_m have been widely used as a reliable diagnostic indicator of damage in response to various stresses such as extreme temperatures, and water and nutrient stress (Close & Beadle, 2003; Epron, Dreyer & Breda, 1992; Gamon & Pearcy, 1989; Groom & Baker 1992; He, Chee & Goh, 1996; Valladares & Pearcy, 1997). Since root-rot pathogens attack the vascular system of plants, responses to infection may be similar to those observed for drought stress. In drought-stressed plants, thylakoid membranes are the primary site of injury which leads to the decline of PS II activity (Dubey, 1997; Mutava, 2009). However, there was no evidence in this study that the decline in PS II activity was associated with parallel reductions in light-saturated photosynthetic rate A_{max}, but this may be because the reductions in F_v/F_m were not yet of sufficient magnitude. Decreases of PS II activity under stress are associated with photoinhibition where free high energy radicals in the thylakoid membranes cause photo-oxidation of the chlorophyll

(Havaux, 1992; Mutava, 2009). Differences between treatments in chlorophyll content at T_2 in this experiment suggested that this may occur; however between treatment reductions in chlorophyll content between T_0 and T_2 were not significantly different.

While decreases in A_{max} between T_0 and T_2 were not significant, it is probable that the reduced rate was a response to seasonal changes in light and temperature as the T_0 measurement was done in mid-spring when the daily light exposure and temperature ranged between 3.1 to 32.8 MJ/m^2 and 10.6 to 30.6°C, respectively, while the T_2 was in late autumn when the daily light exposure and temperature ranged between 2.3 to 19.0 MJ/m^2 and 10.4 to 26.5°C, respectively. Leaves growing in a high light environment attain greater A_{max} than leaves growing in a low light environment (DeJong & Doyle, 1985). Reduced A_{max} can also be caused by reductions in seasonal temperatures (Battaglia, Beadleand & Loughhead, 1996) and overnight frost (Davidson, Battaglia & Close, 2004). Photosynthetic rates have shown to be closely related to chlorophyll content (Boardman, 1977; DeJong & Doyle, 1985), and this is consistent with the reduced chlorophyll content observed in this experiment. Loss of chlorophyll content was also found in *Pinus sylvestris* as seasonal temperatures declined (Ottander, Campbell & Oquis, 1995).

B. Re-isolation from Infected Roots

Root excavation showed that most of the inoculated saplings, both wounded and unwounded, were infected by *A. luteobubalina* (Table 3). Wounded saplings (W-P1 and W-P2) showed 100% and 85.7% infection of *A. luteobubalina* strain-1 and strain-2, respectively; unwounded ones (UW-P1 and UW-P2), both inoculated with *A. luteobubalina* strain-1 and strain-2 showed only 71.4% infection (Table 3); these results confirm that wounding tends to enhance the possibility of infection. Wounded saplings inoculated with both strains of *A. luteobubalina* showed a greater level of infection than unwounded saplings.

Table 3 also shows that 14.3% and 28.6% of the roots of wounded and unwounded control plants (W-P0 and UW-P0), respectively, were infected by other soil fungi. Identification of these confounding fungal isolates was beyond the scope of this study.

In the field, wounding as well as other factors, such as poor planting, poor drainage and soil compaction can contribute to the increased incidence and severity of *Armillaria* root disease (Hadfield et al., 1986). Intact outer bark may play an important role in protecting roots from invasion by pathogens (Wargo & Harrington, 1991). Root grafts, breakage and associated insect feeding can potentially provide entry points for *Armillaria* and other root pathogens (Harrington, 1986; Rizzo & Harrington, 1988; Whitney, 1961). However, Baumgartner and Rizzo (2006) found that wounding the root collar of grapevine rootstocks did not significantly increase the infection rate of *Armillaria mellea* in a greenhouse trial. This suggests that wounding can trigger host defence reactions

Table 3. Percentages of saplings for which pathogens were re-isolated from rootsin each of four categories.

Treatments	Root condition			
	Positively infected	Possibly infected	Infected by other fungi	Uninfected
$UW\text{-}P_0$	0.0	0.0	28.6	71.7
$W\text{-}P_0$	0.0	0.0	14.3	85.7
$UW\text{-}P_1$	71.4	14.3	0.0	14.3
$W\text{-}P_1$	100.0	0.00	0.0	0.0
$UW\text{-}P_2$	71.4	28.6	0.0	0.0
$W\text{-}P_2$	85.7	14.3	0.0	0.0

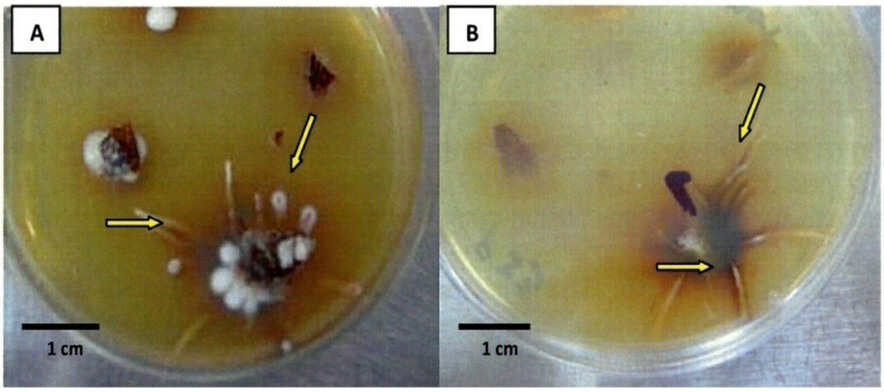

Figure 4. Re-isolated *A.luteobubalina* culture showing typical rhizomorphs (yellow arrows)
Remarks: (A)surface; (B) inverted

(Eyles, Bonello, Ganley & Mohammed, 2010), for example, the production of enzymes that function in lignin synthesis which leads to the reinforcement of the damaged cell wall (Baron & Zambryski, 1995) and/or the release of lytic enzymes or toxic secondary metabolites that may limit hyphal penetration of the inner bark (Wargo & Harrington, 1991). The possibility that wounding may have stimulated a defence reaction of the host in this study was not investigated.

Fungal infection was confirmed by the presence of mycelial fans and lesions on the root or root collar (Figure 3). Fungal cultures that had been isolated from the inoculated and symptomatic plants confirmed the presence of *A. luteobubalina* (Figure 4). The viability of the *A. luteobubalina* isolates on the *E. globulus* inoculum rods after being buried for seven months was low. Positive re-isolations of *A. luteobubalina* from these rods were obtained for three pots only and all were *A. luteobubalina* strain-1; re-isolations from inoculum rods carrying *A. luteobubalina* strain-2 were unsuccessful.

Similarly, there was a low level of successful re-isolations from the inoculum rods that had pseudosclerotial plates. Difficulties in re-isolating from pseudosclerotial plates can be understood since they are an immobile/inactive phase of *Armillaria* and had probably developed in response to the occupation of the rods by decomposing soil fungi (Dowson, Rayner & Boddy, 1988).

This study confirmed the challenges of detecting the presence of root-rot disease during early infection. Among the physiological variables measured in this study, there was some evidence that at least one photosynthetic variable (*i.e.* F_v/F_m) may provide an early indicator of infection. Root and root collar examination remains the most reliable way to judge whether or not trees are infected. For *Armillaria* root disease, the production of characteristic mycelial fans can be also be used as a diagnostic feature.

IV. CONCLUSION

Physiological responses to artificial infection with the root-rot pathogen, *A. luteobubalina* were examined in *E. nitens* saplings. Among the physiological variables measured, we found that Fv/Fm was the most sensitive parameter for the early detection of root-rot disease. In particular, a significant difference in Fv/Fm between the unwounded control (UW-P0) and other treatments was observed. Chlorophyll content and A_{max} decreased for all trees, including controls during the seven months period and most likely reflected changes in season rather than treatment effects. Successful re-isolation of the root pathogen *A. luteobubalina* from inoculated symptomatic roots confirmed that the physiological changes were associated with the infection by this fungal pathogen. However, the functional changes that led to a reduction in PS II efficiency in the inoculated saplings require further investigation. The finding from this study demonstrated that several months may be required following infection before any physiological changes can be detected. Root-rot is known to be a latent disease that may be present in plants for an extended period without any noticeable expression of symptoms. Longer periods of observation than were possible in this experiment are recommended for further research with a similar focus of interest.

ACKNOWLEDGEMENT

This study was financially supported by Australian Centre for International Agricultural Research (ACIAR) through the John Allwright Fellowship and Project FST/2003/048. We thank Dr. Morag Glen, for assistance with molecular analysis and Dr. Alieta Eyles for assistance with physiological analysis and revision on an earlier draft of the manuscript. Support from numerous staff in CSIRO Ecosystem Sciences is much appreciated.

REFERENCES

Agustini, L. (2010). Signs and symptoms of root rot in *Eucalyptus pellita* plantations in Indonesia (Thesis). University of Tasmania. Retrieved from http://ecite.utas.edu.au/rmdb/ecite/q/ecite_view_author/21767

Baron, C., & Zambryski, P.C. (1995). The plant response in pathogenesis, symbiosis and wounding: variation on a common theme? *Annual Review of Genetics*, *29*, 107–129.

Barry, K.M., Stone, C., & Mohammed, C.L. (2008). Crown-scale evaluation of spectral indices for defoliated and discolouredeucalypts. *Int. J. Remote Sens*, *29*, 47–69.

Battaglia, M., Beadleand, C., & Loughhead, S. (1996). Photosynthetic temperature responses of *Eucalyptus globulus* and *Eucalyptus nitens*. *Tree Physiology*, *29*, 81–89.

Baumgartner, K., & Rizzo, D.M. (2006). Relative resistance of grapevine rootstocks to Armillaria root disease. *Journal of Ecology & Viticulture*, *57*, 408–414.

Beadle, C. (2000). Physiology of eucalypts in relation to disease. In P.J. Keane, G.A. Kile, P.D. Podge, & B.N. Browns (Eds.), *Diseases and Pathogens of Eucalyptus* (pp. 61–70). Collingwood: CSIRO Publishing.

Berger, S., Papadopoulos, M., Schreiber, U., Kaiser, W., & Roitsch, T. (2004). Complex regulation of gene expression, photosynthesis and sugar level by pathogen infection in tomato. *Physiologia Plantarum*, *122*, 419–428.

Berger, S., Sinha, A.K., & Roitsch, T. (2007). Plant physiology meets phytopathology: plant primary metabolism and plant-pathogen interaction. *Journal of Experimental Botany*, *58*, 4019–4026.

Boardman, N.K. (1977). Comparative photosynthesis of sun and shade plants. *Annual Review of Plant Physiology*, *28*, 355–377.

Bonfig, K.B., Schreiber, U., Gabler, A., Roitsch, T., & Berger, S. (2006). Infection with virulent and avirulent P. syringae strains differentially affects photosynthesis and sink metabolism in Arabidobsis leaves. *Planta*, *225*, 2006, 1–12. doi:10.1007/s00425-006-0303-3.

Brown, N.A., Antoniw, J., & Hammond-Kosack, K.Z. (2012). The predicted secretome of the plant pathogenic fungus *Fusarium graminearum*: A refined comparative analysis. *PLos ONE*, *7*, 4, e33731. doi:10.1371/journal.pone.0033731.

Chou, H., Bundock, N., Rolfe, S., & Scholes, J. (2000). Infection of *Arabidopsis thaliana* leaves with Albugo candida (white blister rust) causes a reprogramming of host metabolism. *Mol. Plant Pathol*, *1*, 99–113.

Close, D.C., & Beadle, C.L. (2003). Chilling-dependent photoinhibition, nutrition and growth analysis of Eucalyptus nitens seedlings during establishment. *Tree Physiology*, *23*, 217–226.

Davidson, N.J., Battaglia, M., & Close, D.C. (2004). Photosynthetic responses to overnight frost in *Eucalyptus nitens* and *E. globulus*. *Trees*, *18*, 245–252.

DeJong, T.M., & Doyle, J.F. (1985). Seasonal relationships between leaf nitrogen content (photosynthetic capacity) and leaf canopy light exposure in peach (*Prunus persica*). *Plant, Cell and Environment*, *8*, 701–706.

Dowson, C.G., Rayner, A.D.M., & Boddy, L. (1988). he form and outcome of mycelial interactions involving cord-forming decomposer basidiomycetes in homogeneous and heterogeneous environments. *New Phytologist*, *109*, 423–432.

Dubey, R. (1997). Photosynthesis in plants under stressful condition. In M. Pessarakli (Ed.), *Handbook of photosynthesis* (p. 1027). New York: Marcel-Dekker Inc.

Epron, D., Dreyer, E., & Breda, N. (1992). Photosynthesis of oak trees (*Quercus petraea* (Matt) Liebl.) during drought stress under field condition: Diurnal course of net CO_2 assimilation and photochemical efficiency of photosystem II. *Plant, Cell and Environment*, *15*, 809–820.

Eyles, A., Bonello, P., Ganley, R., & Mohammed, C. (2010). Induced resistance to pests and pathogens in trees. *New Phytologist*, *185*, 893–908.

Farid, A.M., Lee, S.S., Maziah, Z., Rosli, H., & Norwati, M. (2006). Root rot in tree species other than Acacia. In K. Potter, A. Rimbawanto, & C. Beadle (Eds.), *Heart rot and root rot in tropical Acacia plantations. Proceedings of a workshop held in Yogyakarta, Indonesia, 7-9 February 2006* (*ACIAR Proceedings No. 124*) (pp. 60–66).

Gamon, J. A., & Pearcy, R.W. (1989). Leaf movement, stress avoidance and photosynthesis in *Vitis californica*. *Oecologia*, *79*, 475–481.

Goicoechea, N., Aguirreolea, J., Cenoz, S., & Garcia-Mina, J. M. (2001). Gas exchange and flowering in Verticillium-wilted pepper plants. *J. Phytopatho*, *149*, 281–286.

Groom, Q.J., & Baker, N. R. (1992). Analysis of light-induced depression of photosynthesis in leaves of wheat crop during the winter. *Plant Physiology*, *100*, 1217–1223.

Guest, D., & Brown, J. (1997). Infection process. In J. F. Brown & H. J. Olsen (Eds.), *Plant pathogens and plant diseases* (pp. 245–262). Armidale, Australia: University of New England.

Gunthardt-Goerg, M.S., & Vollenweider, P. (2007). Linking stress with macroscopic and microscopic leaf response in trees: New diagnostic perspectives. *Environmental Pollution*, *147*, 467–488.

Hadfield, J.S., Goheen, D.J., Filip, G.M., Schmitt, C.L., & Harvey, R.D. (1986). *Root diseases in Oregon and Washington conifers* (R6-FPM-250-86). Washington D.C.: USDA Forest Service, PNW Region.

Harrington, T.C. (1986). Growth decline of wind-exposed red spruce and balsam fir in the White Mountains. *Canadian Journal of Forest Research*, *16*, 232–238.

Havaux, M. (1992). Stress tolerance of photosystem II in vivo: antagonistic effects of water, heat and photoinhibition stresses. *Plant Physiology*, *100*, 424–432.

He, J., Chee, C.W., & Goh, C.J. (1996). Photoinhibition of Heliconia under natural tropical condition: The importance of leaf orientation for light interception and leaf temperature. *Plant, Cell and Environment*, *19*, 1238–1248.

Lichtenthaler, H.K., & Buschmann, C. (2001). Chlorophylls and carotenoids. Measurements and characterisation by UV-VIS. *Current Protocols in Food Analytical Chemistry* (pp. F4.3.1–F4.3.8). Madison: John Wiley & Sons.

Lopes, D.B., & Berger, R.D. (2001). The effects of rust and anthracnose on the photosynthetic competence of diseased bean leaves. *Phytopathology*, *91*, 212–220.

Luyssaert, S., Raitio, H., Vervaeke, P., Mertens, J., & Lust, N. (2002). Sampling procedure for the foliar analysis of deciduous trees. *J. Environ. Monit*, *4*, 858–864.

Mansilla, J.P., Aguin, O., & Sainz, M.J. (2001). A fast method for production of Armillaria inoculum. Mycologia. *Mycologia*, *93*, 612–615.

Martin, I., Alonso, N., Lopez, M.C., Prieto, M., Cadahia, C., & Eymar, E. (2007). Estimation of leaf, root, and sap Nitrogen status using the SPAD-502 chlorophyll meter for ornamental shrubs. *Communication in Soil Science and Plant Analysis*, *38*, 1785–1803.

Meyer, S., Saccardt, A.K., Rizza, F., & Genty., B. (2001). Inhibition of photosynthesis by Colletotrichum lindemuthianum in bean determined by chlorophyll fluorescence imaging. *Plant Cell Environ.*, *24*, 947–955.

Mohammed, C., Rimbawanto, A., & Page, D. (2014). Management of basidiomycete root- and stem-rot diseases in oil palm, rubber and tropical hardwood plantation crops. *For. Pathol*, *In press.*

Morrison, D.J., Williams, R. E., & Whitney, R.D. (1991). Infection, disease development, diagnosis, and detection. In C. G. Shawn III & G. . Kile (Eds.), Armillaria root disease (*Agricultural Handbook No.691*) (pp. 62–75). Washington D.C.: USDA Forest Service.

Mutava, R. N. (2009). *Charachterization of grain sorghum for physiological and yield traits associated with drought tolerance* (thesis). Kansas State University, USA.

Omdal, D. W., Shaw III, C. G., & Jacobi, W. R. (2004). Symptom expression in conifers infected with *Armillaria ostoyae* and *Heterobasidion annosum*. *Can. J. For. Res.*, *34*, 1210–1219.

Ottander, C., Campbell, D., & Oquis, G. (2004). Seasonal changes in photosystem II organisation and pigment composition in *Pinus sylvestris*. *Plant, Cell and Environment*, *197*, 176–183.

Pinkard, E.A., & Mohammed., C.L. (2006). Photosynthesis of *Eucalyptus globulus* with Mycosphaerella leaf disease. *New Phytologist*, *170*, 119–127.

Rizzo, D.M., & Harrington, T.C. (1988). Root movement and root damage of red spruce and balsam fir on subalpine sites in the White Mountains, New Hampshire. *Canadian Journal of Forest Research*, *18*, 991–1001.

Robert, C., Bancal, M., Nicolas, P., & Lannou, C.B.N. (2004). Analysis and modelling of effects of leaf rust and Septoria tritici blotch on wheat growth. *Journal of Experimental Botany*, *55*, 1079–1094.

Rodriguez-Moreno, L., Pineda, M., Soukupova, J., Macho, A.P., Beuzon, C.R., Baron, M., & Ramos, C. (2007). Early detection of bean infection by Pseudomonas syringae in asymtomatic leaf areas using chlorophyll fluorescence imaging. *Photosynth. Res.* doi:10.1007/s11120-007-9278-6.

Sharma, P.K., & Hall, D. (1992). Changes in carotenoid composition and photosynthesis in sorghum under high light and salt stress. *J. Plant Physiol*, *140*, 661–666.

Shaw III, C.G., & Kile, G.A. (Eds.). (1991). *Armillaria root disease* (*Agricultural Handbook No. 691*) (p. 233). Washington D.C.: USDA Forest Service.

Sigh, A.K., & Dubey, R.S. (1995). Changes in chlorophyll a&b contents and activities of photosystem 1 & 2 in rice seedlings induced by NaCl. *Photosynthetic*, *31*, 489–499.

Stone, C., Coops, N., & Culvenor., D. (2000). Conceptual development of a Eucalypt Canopy Condition Index using high resolution spatial and spectral remote sensing imagery. *Journal of Sustainable Forestry*, *11*, 23–45.

Valladares, F., & Pearcy, R.W. (1997). Interaction between water stress, sun-shade acclimation, heat tolerance and photoinhibition in the sclerophyll *Heteromeles arbutifolia*. *Plant, Cell and Environment*, *20*, 25–36.

Wargo, P.M., & Harrington, T.C. (1991). Host stress and susceptibility. In S.I.C.G. & G.A. Kile (Eds.), *Armillaria root disease* (*Agricultural Handbook No. 691*) (pp. 88–101). Washington D.C.: USDA Forest Service.

Whitney, R.D. (1961). Root wounds and associated root rots of white spruce. *Forestry Chronicle*, *37*, 401–411.

Indonesian Journal of Forestry Research Vol. 2, No. 1, April 2015, 21-29 ISSN: 2355-7079 / E-ISSN: 2406-8195

CENTRAL KALIMANTAN'S FAST GROWING SPECIES: SUITABILITY FOR PULP AND PAPER

Danang S. Adi[1,*], Ika Wahyuni[1], Lucky Risanto[1], Sri Rulliaty[2], Euis Hermiati[1], Wahyu Dwianto[1] and Takashi Watanabe[3]

[1]Research Center for Biomaterials, Indonesian Institute of Sciences, Cibinong Science Center, Bogor 16911, Indonesia
[2]Forestry Engineering and Forest Products Processing, Research and Development Center, Jl. Gunung Batu No.5, Bogor 16610, Indonesia
[3]Research Institute for Sustainable Humanosphere, Kyoto University, Gokasho, Uji, Kyoto, Japan

Received: 21 August 2014, Revised: 6 January 2015, Accepted: 16 January 2015

CENTRAL KALIMANTAN'S FAST GROWING SPECIES: SUITABILITY FOR PULP AND PAPER
Recent studies of fast growing species grown in PT. Sari Bumi Kusuma, Central Kalimantan, show that based on their fiber dimensions there are five species, namely *Endospermum diadenum*, *Dillenia* spp., *Adinandra dumosa*, *Adiandra* sp., and *Nauclea junghuhnii* with good potential for pulp and paper production. The fiber length of those five wood species are was more than 2,200 μm on average. This paper studies the physical properties, fiber dimensions and their chemical contents to predict the paper and pulp quality. The result shows that all of the species were classified in the medium to high density category. All species were classified into the first class quality for pulp and paper. Based on chemical contents, *Dillenia* sp. is the most suitable species due to its high value of holocellulose and α-cellulose, low lignin content, and its fiber length is about 3,119 μm on average. *A. dumosa* also has good opportunities because it had the longest fiber lengths (3,137 μm on average) and high value of holocellulose, even though it has the highest lignin content. While *Nuclea junghuhnii* is less suitable due to low values of holocellulose and α-cellulose.

Keywords: Fast growing wood, fiber characteristic, density, chemical composition, pulp and paper

KAYU CEPAT TUMBUH DARI KALIMANTAN TENGAH: KESESUAIANNYA UNTUK BAHAN BAKU PULP DAN KERTAS. Berdasarkan penelitian sebelumnya terhadap 30 jenis kayu cepat tumbuh dari PT Sari Bumi Kusuma, Kalimantan Tengah menunjukkan terdapat 5 jenis kayu yang berpotensi sebagai bahan baku pulp dan kertas. Panjang serat dari kelima jenis kayu, yaitu Endospermum diadenum*,* Dillenia sp.*,* Adinandra dumosa*,* Adinandra sp.*, and* Nauclea junghuhnii *lebih dari 2.200 μm. Tulisan ini mempelajari potensi penggunaan kelima jenis kayu tersebut untuk bahan baku pulp dan kertas. Hasil penelitian menunjukkan bahwa kelima jenis kayu mempunyai kerapatan medium sampai berat. Berdasarkan penilaian pada dimensi seratnya, kelima jenis kayu dapat diklasifikasikan dalam kelas kualitas satu untuk pulp dan kertas. Berdasarkan kandungan kimia kayunya,* Dillenia sp. *merupakan jenis yang paling potensial sebagai bahan pulp dan kertas karena memiliki panjang serat 3.119 μm, kandungan holoselulosa dan a selulosa tinggi, serta kandungan lignin yang rendah.* A. dumosa *juga berpotensi karena seratnya terpanjang, namun kandungan lignin terbanyak diantara kelima jenis kayu tersebut. Sedangkan* Nauclea junghuhnii *adalah jenis yang paling rendah potensinya untuk dijadikan bahan baku pulp dan kertas karena rendahnya kandungan holoselulosa dan a selulosa.*

Kata kunci: Kayu cepat tumbuh, karakteristik serat, kerapatan, kandungan kimia, pulp dan kertas

[*]Corresponding author: danang@biomaterial.lipi.go.id

I. INTRODUCTION

In the last few decades, Indonesia's pulp and paper industries have grown rapidly and have the potential to become one of the biggest pulp and paper industries in the world. In 2011, these industries produced about 7.3 million ton pulp per year from 7.9 million ton of the mills' production capacities and 10.7 million paper per year from 12.99 million ton of mills' production capacities. These production figures helped Indonesia to become the 9th biggest pulp and paper producer in the world and the 3rd of the Asian countries (Malau & Prasetyo, 2012). These industries have a shining prospect in the future because of the increasing demand for pulp and paper products. The Directorate General of Manufacture Based Industry, Ministry of Industry mentioned that global demand for paper has grown by 2.1% annually; However, in the developing countries it has grown by 4.1% (Malau & Prasetyo, 2012; Koran Jakarta, 2012).

Domestic paper demand was also predicted to grow in the future. In 2011, Indonesia's paper consumption was about 30 kg/capita/year. It is lower than that of ASEAN's which was about 50-60 kg/capita/year and much lower than Europe which was about 200 kg/capita/year (Karina, 2012; Neraca, 2012). The global population growth as well as economic growth in a developing country such as Indonesia is believed to lead to the enhancement of paper needs.

Indonesia covers tropical area where trees for pulp and paper or other purposes grow well. Some species, such as Acacia wood, which are used as primary raw materials for pulp production, can grow fast (it can reach 265 m^3/ha at 8 years) and has a short rotation period (Soemitro, 2004). Well known primary raw materials for pulp and paper industries in Indonesia are *Acacia mangium* (Marsoem, 2004) and *Pinus merkusii* (Martawijaya, Kartasujana, Mandang, Prawira & Kadir, 1989). Marsoem (2004) reported that a nine year old *A. mangium* plantation has the values of specific gravity, fiber length, Runkel ratio, and felting power of 0.36-0.53 g/cm^3, 0.78-1.12 mm, 0.30-0.45 and 40.5-45, respectively. *A. mangium* from Central Kalimantan, with the diameter of 14 cm and the ages of 7-10 year, has specific gravity, fiber length, Runkel ratio, and felting power of 0.41g/cm^3, 1.314 mm, 0.17 and 43.41, respectively (Adi et al., 2014). *Pinus merkusii* has values of specific gravity, fiber length, Runkel ratio and felting power of 0.55 g/cm^3, 5.57 mm, 0.24, and 111, respectively. Some wood species which have potential for pulp and paper production are also grown in the tropical Indonesian Forest. The pulp and paper properties may be higher than that of acacia and pine wood (Sable et al., 2012).

Recent research result showed that the five fast growing species grown in PT. Sari Bumi Kusuma (PT SBK) can potentially be developed as pulp and paper material, with the average fiber length greater than 2,200 μm and the wood of medium density (Adi et al., 2014). For tropical hardwood species this long fiber length is uncommon. Moreover, these fiber lengths were close to that of softwood species, such as Pine wood (Sable et al., 2012).

Fast growing species are classified as tree which have an annual mean increment of more than 1 cm per year (Dwianto, Amin, Dharmawan & Wahyuni, 2008). The five species studied are generally grow well in the open land after logging activity in the secondary forest at PT SBK's concession area. These species were used and planted by the nursery division of PT SBK (the year of planting is about 2003-2005) for soil reclamation in the concession area. With the diameter of more than 10 cm, these species have an average annual mean increment at least 1 cm/year, so it could be classified as fast growing wood species. For soil reclamation purposes these five species are not included in the logging activity. Neither these species were included as mixed wood forest class in the logging plan.

It is a good opportunity to develop these species to plantation forest since their abilities to grow in open and marginal lands. Combined with sustainable management of plantation forest, such as continuous and balanced planting, harvesting and replanting, the supply of wood to meet the wood demand for any purposes can be better secured. Generally, fast growing wood species have low quality due to their low properties values, such as wood density, strength, and durability (Panshin & de Zeeuw, 1980; Bowyer, Haygreen & Schmulsky, 2003). Therefore, the utilization of fast growing wood species has been limited to paper, pulp, and fuel wood (Kojima et al., 2009a). Fiber characteristics and fiber derived value are important to predict the suitability for pulp and paper, as well as paper sheet properties, e.g. tear and burst index, and tensile strength (Biermann, 1996; Bowyer et al., 2003; Ververis, Georghiou, Christodoulakis, Santas & Santas, 2004).

Parameters of wood properties, such as fiber characteristics, wood density as well as chemical composition, can be used to predict the pulp and paper quality. The chemical composition of wood: holocellulose, lignin, and α-cellulose are important parameters in pulp and paper making (Panshin & de Zeeuw, 1980; Biermann, 1996; Bowyer et al., 2003; Ververis et al., 2004). This paper estimates the three wood parameters for pulp and paper including: fiber characteristic, wood density and chemical content.

II. MATERIAL AND METHOD

A. Sampling Method

The wood species were taken from concession area at KM 35, Camp Nanga Nuak, PT SBK, Central Kalimantan (111054' E - 112026' E and 00038' S - 01007' S), Indonesia in March 2012. Species studied were *Endospermum diadenum* (dbh 12 cm), *Dillenia* sp. (dbh 18 cm), *Adinandra dumosa* (dbh 19.6 cm), *Adinandra* sp. (dbh 13.5 cm), and *Nauclea junghuhnii* (dbh 19.1 cm). *A. mangium* (dbh 14 cm) also was taken from the same place. These trees then were cut into discs with the thickness of 6-8 cm, beginning from 30 cm above the ground up to the diameter at breast high (Figure 1).

For each species only one tree was felled, and 10-15 discs from that tree were used to analyse its properties. The discs were then sawn for wood density analysis, and also for chips and meals. Randomly, chips were taken and would be used for fiber maceration, whereas the wood powders were used for chemical analysis. In the field, wood identification was determined using local name. Some part of the trees, such as leaf, flower, and fruit were taken to herbarium to determine its scientific name. Tree species identification was conducted from herbarium identification in Herbarium Bogoriense, Research Center, LIPI. In order to support the species identification, wood identification was also conducted in The Forestry Engineering and Forest Product Processing R&D Center, Ministry of Forestry.

B. Density and Fiber Characteristics

Wood density and moisture content analysis were conducted by referring to British Standard 373-1957 (BSI 07-1999). The maceration of the five woods was conducted to analyse fiber characteristics e.g. fiber length and fiber derived value. The method was conducted by Franklin's method, utilizing equal parts of hydrogen peroxide and acetic acid glacial, and then heated at 600°C for 1-2 days (Dodd, 1986).Variables tested for fiber derived values determination were Runkel ratio, felting power, Muhlsteph ratio, coefficient of rigidity, and flexibility ratio (Silitonga, Siagian & Nurahman, 1972; Ververis et al., 2004). *Acacia mangium* and *Pinus merkusii* were used as a comparison of the five species studied. The results were then analysed according to Vademiecum Kehutanan (1976) and Smook (1997) (Tabel 1).

C. Chemical Analysis

The woods were grinded into 40-60 mesh sizes meals. The parameters of chemical analysis i.e. extractives soluble in alcohol-benzene, holocellulose, α-cellulose, and lignin contents were determined according to the Mokushitsu Kagaku Jiken Manual (2000). Extraction were performed in ethanol: benzene 1:2 (v/v) for 6 h. Holocellulose was determined by using 1.5 g of the extracted wood meals. The samples were then treated in 90 ml of distilled water (aquades), 2.4 ml $NaClO_2$ 25% and 0.12 ml of acetic acid. Then, they were boiled in the water bath at 80°C. 2.4 ml $NaClO_2$ 25% and 0.12 ml

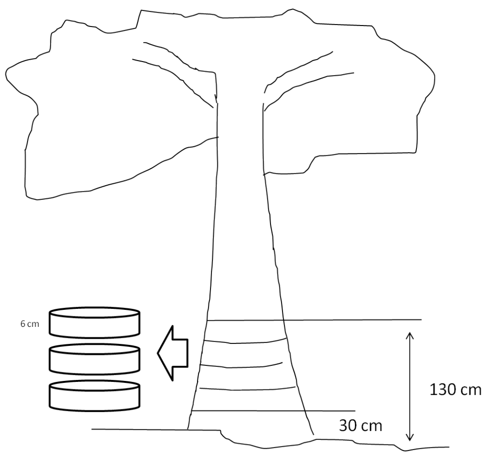

Figure 1. Scheme of wood sample

Table 1. Classification of fiber length and fiber derived value by Vademecum Kehutanan

Parameter	Class I		Class II		Class III		Class IV		Hardwood*	Softwood*
	Score									
Fiber Length (μm)	2200	100	1600-2200	75	900-1600	50	900	25		
Runkel ratio	0.25	100	0.2-0.5	75	0.5-0.1	50	1	25	0.4-0.7	0.35
Felting power	90	100	70-90	75	40-70	50	40	25	55-75	95-120
Flexibility ratio	0.8	100	0.6-0.8	75	0.4-0.6	50	0.6	25	55-70	75
Coefficient of rigidity	0.1	100	0.1-0.15	75	0.15-0.2	50	0.2	25		
Muhlsteph ratio	30%	100	30-60 %	75	60-80 %	50	80%	25		
Total Score	451-600		301-450		151-300		150			

Source: *Smook (1997), Vadamecum Kehutanan (1976)

of acetic acid was added to the sample until the color became white. For α-cellulose analysis, 0.5 g of holocelullose were soaked in 12.5 ml NaOH 17.5 %, and stirred for 30 minutes. Then, to the mixture was added 12.5 ml distilled water (aquades) and was filtered using fritted-glass filtering crucible (IG3). After washing the mixture using distilled water (aquades ",") 20 ml of acetic acid were added for the last washing. Klason Lignin was analyzed by using 0.5 g of the previously extracted wood meal. The meals were soaked in 7.5 ml H_2S0_4 72 %, then was stirred for 4 hours. After that, the sample was hydrolysed by 280 ml of distilled water (aquades) and boiled at autoclave 121°C for 15 minutes, then was filtered using fritted-glass filtering crucible.

III. RESULT AND DISCUSSION

The density of wood based on Panshin and de Zeeuw (1980) are classified as medium density (0.36-0.50) *i.e Endospermum diadenum* and *Adinandra* sp. and also high density (>0.50) *i.e Dillenia* sp., *Adinandra dumosa*, *Nauclea junghuhnii*. Generally, the higher the density of wood, the higher the yield of the pulp. (Bowyer et al., 2003). The high density of hardwood species indicates that there are high content of cellulose in the wood, which can increase the yield of the pulp (Casey, 1980). The density of wood are reported to have effect on yield, transportation and production cost. Panshin and de Zeeuw (1980) has reported that wood density may affect the quality of pulp, due to cell size and variations in the cell wall thickness. The value of wood density, fiber length and fiber derivative (Table 2 and 3) shows that

Table 2. Wood density, derivative value and scoring of species studied

Species	Fiber length (µm)	Density	Total Score	Class
Endospermum diadenum	2631	0.36	550	I
Dillenia sp.	3119	0.62	550	I
Adinandra dumosa	3137	0.53	550	I
Adinandra sp.	2868	0.44	550	I
Nauclea junghuhnii	2462	0.56	550	I
Acacia mangium[1*]	1071	0.68		
Pinus merkusii[2*]	5457	0.55		
Pinus silvestris[3*]	2150	0.455		
Acacia mangium[4*]	1120	0.53		
Acacia mangium[5*]	1314	0.41	550	I

Source: [1*]Kojima et al., (2009b); [2*]Martawijaya et al., (1989); [3*]Sable et al., (2012); [4*]Marsoem, (2004); [5*]Adi et al., (2014)

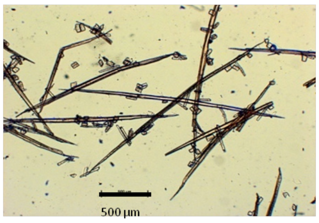

Figure. 2. *Endospermum diadenum*

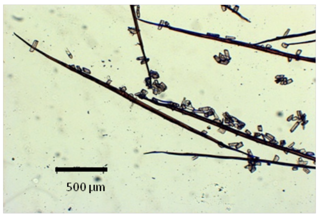

Figure 3. Dillenia sp.

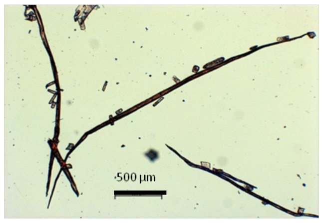

Figure 4. Adinandra dumosa

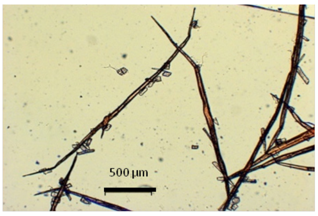

Figure 5. Adinandra sp.

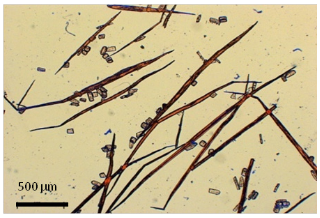

Figure 6. Nauclea junghuhnii

these five species as raw material for pulp and paper can be classified into the class I category. Moreover, these species tend to have the same properties as the softwood species, i.e. long fiber length and also low value of Runkel ratio, but the value of felting power is lower than that of softwood species. Generally, fiber length of hardwood species is shorter than that of softwood species (Biermann, 1996). Fibers of each species is shown in Figures 2-6.

The result is interesting as these five hardwood species from PT SBK has comparatively long fibers, the longest is *A. dumossa* (3.1 mm). Even concerning the levels of fiber lengths these species have similarities to the softwood species *Pinus silvestris* (2.1 mm), but the level of fiber length is lower than that for *Pinus merkusii* from Indonesia. *Acacia mangium*, which is the main raw material for pulp and paper production in Indonesia, has lower fiber length than these five species from Central Kalimantan. It seems that these species are promising as alternative wood sources for pulp and paper. The density of wood also has similarity with that of the Mangium wood from the same place (Central Kalimantan) or another place.

Fiber derived values (Table 2 and 3) show that these five species can be classified in the first quality for pulp and paper production.

Table 3. Fibre dimensions and derived values of fast-growing wood species from Central Kalimantan

Species	Fibre Dimensions (μm)				Fibre Derived Value				
	Fibre length	Diameter	Lumen	Cell wall thickness	Runkel ratio	Felting power	Flexibility ratio	Coefficient of rigidity	Muhlsteph ratio
E.diadenum	2631	52.37	47.07	2.65	0.12	52.93	0.90	0.05	19.34
Dillenia sp.	3119	54.62	48.85	2.89	0.12	55.21	0.89	0.05	20.16
A.dumosa	3137	60.77	55.15	2.81	0.11	52.78	0.91	0.05	17.77
Adinandra sp.	2868	59.41	52.99	3.21	0.12	49.44	0.89	0.05	20.48
N.junghuhnii	2462	43.89	37.97	2.96	0.16	57.13	0.86	0.07	25.22
A. mangium	1314	30.75	26.40	2.18	0.17	43.41	0.86	0.07	26.49

Moreover, the value of Runkel ratio, which is the most important fiber derived value, is close to that of *Pinus merkusii* (0.24). Runkel ratio indicates fiber to fiber bonding (Biermann, 1996, Bowyer et al., 2003). Runkel ratio can be used to determine the suitability of fiber for pulp production (Ogbonnaya, Roy-Macauley, Nwalozie & Anneros, 1997). It means that the lower the value of Runkel ratio, the higher is the contact area of fiber to fiber and the greater is the burst and tensile strength. According to Smook (1997), the value of flexibility ratio also has similarity with the softwood species. Flexibility ratio was reported to influence the burst and tensile strength as well as folding endurance (Ververis et al., 2004). Therefore, it can be assumed that these five species will have high burst index, tensile index, and folding endurance due to the high value of flexibility ratio.

Chemical properties of these fast growing wood (Figure 7) show that holocellulose content were relatively lower than those of Acacia wood, which was reported by Marsoem (2004), but it was similar with Acacia wood from PT SBK. Holocellulose is a term for the entire carbohydrate fraction of wood, i.e. cellulose and hemicelluloses (Fengel & Wegener, 1995; Biermann, 1996). Holocellulose is a carbohydrate fraction which is produced by wood delignification (Fengel & Wegener, 1995). Generally, pulping process is defined as removing lignin by taking the fiber (cellulose) from the lignocellulosic material. This means that the higher holocellulose content, the higher pulp yield from the pulping process. Hemicellulose reportedly could increase the properties of paper sheet, e.g. burst, tear, and tensile strength (Bierman, 1996). Figure 7 shows that four fast growing woods contain about 70 % of holocellulose. Thus, it can be predicted that the yield of pulping from these species are nearly similar to those from Acacia wood. The lowest holocellulose content is found in *Nauclea junghuhnii* (62.73 %) and is predicted to have lower pulp yield than the others.

Alpha cellulose content is the most important chemical component for pulp and paper sheet. Generally, it is considered that pure cellulose or α-cellulose is the substance in the wood fiber affecting most on the paper's strength, fiber bonding, and the characteristic of the paper sheet. Hydrogen bonding of OH groups in the cellulose could influence the physical properties of paper sheet (Biermann, 1996). The result shows that the α-cellulose content in the 5 investigated species is lower than those of in Acacia woods. However, α-cellulose content of these species was near to 40 %, thus, it has the potential to be used as raw material for pulp and paper production. Nieschlag et al. (1960) in Ververis et al. (2004) proposed that plant materials with a α-cellulose content of 34 % and more were characterized as promising for pulp and paper manufacturing from a chemical composition point of view. These five species have potential to produce high tear strength of pulp or paper due to their long fiber lengths and the low Runkel ratio.

Lignin contents of these five fast growing wood species were higher than those of Acacia and Pine wood (Figure 8). Ververis et al. (2004)

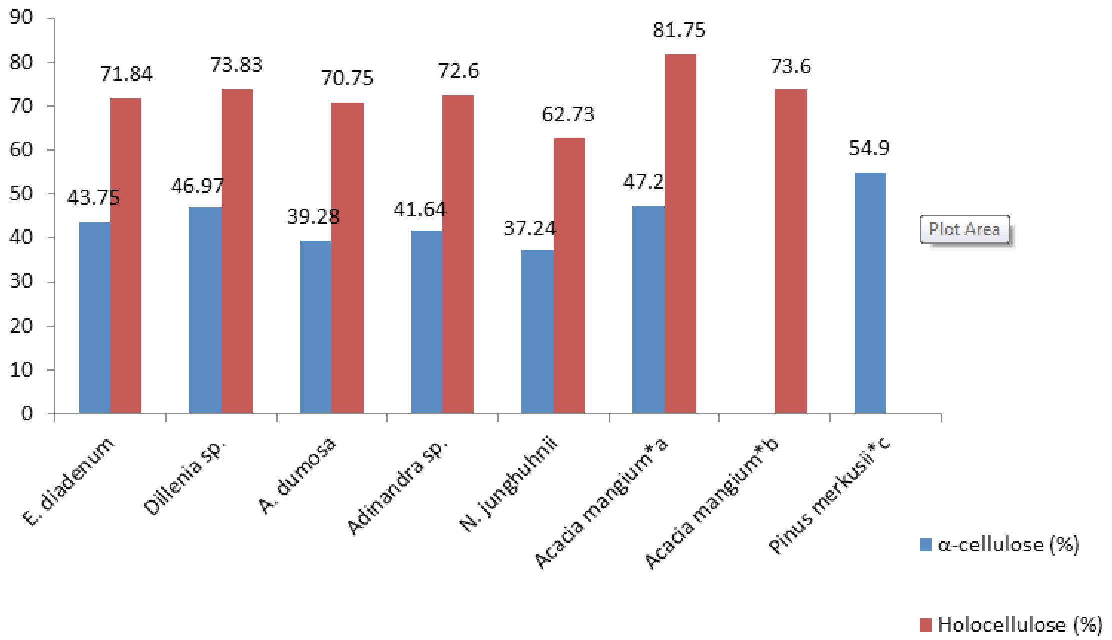

Figure 7. Holocellulose and α-cellulose of fast growing species

Source : a) Marsoem (2004) b) Adi et al. (2014) c) Martawijaya et al. (1989)

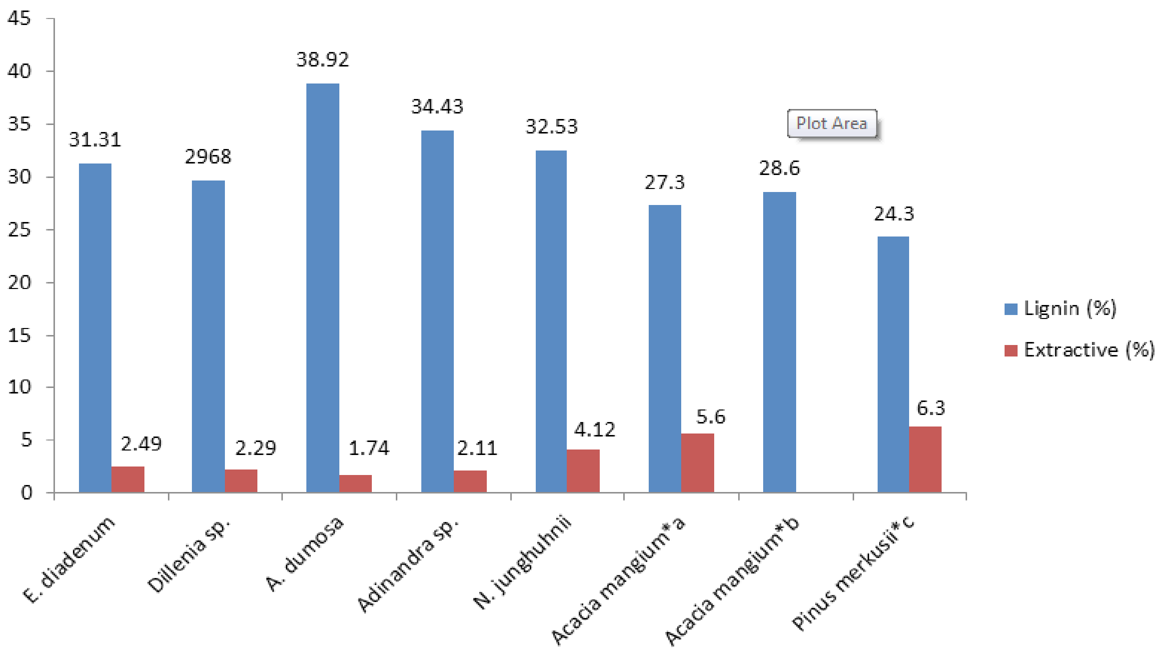

Figure 8. Lignin and extractive content

Source : a) Marsoem (2004) b) Adi et al. (2014) c) Martawijaya et al. (1989)

in their research reported that woods with 30% of lignin content are potential to be used as a raw material for pulp and paper. Lignin is a binder between fiber to fiber in the wood, thus in a pulping process it should be removed. Therefore, the 5 fast growing wood species, especially *Adinandra dumosa* (38%), tend to need more cooking chemicals, time, and temperature during cooking process in the chemical pulping process and more chemicals in the bleaching process than *A. mangium* and *P. merkusii*. Lignin is dominant compound in middle lamella and will be destroyed in the pulping process, while some remaining in the secondary cell wall of the fibers is removed in the bleaching process (Panshin & de Zeeuw, 1980). The high content of lignin, booth in the middle lamella and the secondary cell wall, required more chemical reagent in the pulping and bleaching process. Lignin can decrease the burst strength because it can be a barrier for hydrogen bonding in the fiber formation (Bierman, 1996).

Extractive content can be a problem in the cooking process because it will decrease the ability of chemical cooking. Extractive which is retained in the pulp can be affected to the colour or brightness of pulp and require expensive bleaching for their removal (Panshin & de Zeeuw, 1980). Figure 8 also shows that extractive contents in the five fast growing woods are lower than those in pine and acacia wood. It means that pulp which is made from these species tend to have higher brightness than pulp from pine and acacia wood.

IV. CONCLUSION

According to their fiber characteristics, derived value, and chemical compositions, the five fast growing wood species are potentially suitable as alternative wood resources for pulp and paper industries. *Dillenia* sp. is the most suitable species due to its high value of holocellulose and α-cellulose, low lignin content, and its fiber length of about 3,119 µm on average. *A. dumosa* also has good opportunities because it has 3,137 µm long fiber lengths as well as high holocellulose and α-cellulose, but it has the highest lignin content. High lignin content in these woods can be a problem in the cooking process because it will need more chemicals, time, and temperature during the cooking process. The *Nuclea junghuhnii* is less suitable due to low value of holocellulose and α-cellulose. However, because of their high α-cellulose content (at least 34%) and long fiber length (> 2,200 µm) these species can be considered as raw materials for pulp and paper.

This research only focuses on the wood basic properties. Therefore, further study on pulping process and its quality is needed to confirm the results derived in this study.

ACKNOWLEDGEMENT

This study is partially supported by Japan Science and Technology Agency (JST) under the program entitled "Creation of the Paradigm of Sustainable Use of Tropical Rainforest by the Intensive Forest Management and Advanced Utilization of Forest Resources", sub program B2 "Screening of Fast Growing Wood Species for Bioethanol Production" 2010-2013.

The authors gratefully acknowledge management and staffs of PT Sari Bumi Kusuma, Central Kalimantan, Indonesia, for their assistance in collecting wood samples at the concession area.

REFERENCES

Adi, D., Risanto, L., Damayanti, R., Rulliyati, S., Dewi, L.M., Susanti, R., Watanabe, T. (2013). Exploration of unutilized fast growing wood species from secondary forest in Central Kalimantan: Study on the fiber characteristic and wood density. *Procedia Environmental Sciences*, *20*, 321–237.

Biermann, C.J. (1996). *Hand book of pulping and paper making* (2nd Ed.). California: Academic Press.

Bowyer, J.L., Haygreen, J.G., & Schmulsky, R. (2003). *Forest products and wood science: An introduction* (4th ed.). Iowa, USA: Iowa State Press.

British Standard. (1999). *Methods of testing small clear specimens of timber* (B S 373:1957). The Timber Industry Standards Committee.

Casey, J.P. (1980). *Pulp and paper chemistry and chemical technology, Vol I: Pulping and bleaching* (3rd ed.). New York, USA: Wild Interscience Publication.

Directorate General of Forestry. (1976). *Vademicum kehutanan*. Jakarta: Directorate General of Forestry, Ministry of Agriculture, Indonesia.

Dodd, R.S. (1986). Fiber length measurements system: A review and modification of an existing method. *Wood and Fiber Science*, *18*(2), 276–287.

Dwianto, W., Amin, Dharmawan, T., & Wahyuni, I. (2008). Observation of Fast Growing Wood Species in Purwodadi and Eka Karya Botanical Garden. *Journal of Rimba Kalimantan*, *13*(2), 74–77.

Fengel, D., & Wegener, G. (1995). *Wood: chemical, ultrastructure, reactions*. Yogyakarta: Gajah Mada University Press.

Japan Wood Research Society. (2000). *Mokushitsu kagaku jiken manual*. Japan Wood Research Society.

Karina, S. (2012). Paper and Pulp Consumption to Grow 4% (in Bahasa Indonesia). Retrieved January 12, 2012, from http://economy.okezone.com/read/2012/01/12/320/555991/konsumsi-kertas-dan-pulp-bisa-tumbuh-4.

Kojima, M., Yamamoto, H., Okumura, K., Ojio, Y., Yoshida, M., Okuyama, T., … Hadi, Y. S. (2009a). Effect of the lateral growth rate on wood properties in fast-growing hardwood species. *J Wood Sci*, *55*, 417–424.

Kojima, M., Yamamoto, H., Yoshida, Ojio, Y., & Okumura, K. (2009b). Maturation property of fast-growing hardwood plantation species: A view of fiber length. *J Forest Ecology and Management*, *257*, 15–22.

Koran Jakarta. (2012). RI has opportunities to take over the paper market (in Bahasa Indonesia). *Koran Jakarta, May 30*. Retrieved from http://koran-jakarta.com/index.php/detail/view01/92110

Malau, S., & Prasetyo, B. (2012). Indonesia's opportunities to be the main supplier of pulp and paper (in Bahasa Indonesia). Retrieved May 29, 2012, from http://www.tribunnews.com/bisnis/2012/05/29/peluang-indonesia-jadi-pemasok-utama-pulp-dan-kertas.

Marsoem, S.N. (2004). Utilization of *Acacia mangium* from Plantation Forest. In E. B. Hardiyanto & H. Arisman (Eds.), *Development of* Acacia mangium *plantation forest: an experience in PT Musi Hutan Persada, South Sumatra (in Bahasa Indonesia)*. Yogyakarta: Polydoor Press.

Martawijaya, A., Kartasujana, I., Mandang, Y.I., Prawira, S.A., & Kadir, K. (1989). *Indonesian Wood Atlas, Volume I* (in Bahasa Indonesia). Bogor: Balai Penelitian dan Pengembangan Kehutanan, Departemen Kehutanan.

Neraca. (2012). During 2012, Paper industries has been projected to grow low (in Bahasa Indonesia). Retrieved January 12, 2012, from http://www.neraca.co.id/harian/article/8776/Sepanjang.2012.Industri.Kertas.Diproyeksikan.Tumbuh.Tipis.

Ogbonnaya, C.I., Roy-Macauley, H., Nwalozie, M. C., & Anneros, D.K.M. (1997). Physical and histochemical properties of kenaf (*Hibiscus cannabinus* L.) grown under water deficit on a sandy soil. *Industrial Crops and Products*, *7*, 9–18.

Panshin, A., & de Zeeuw, C. (1980). *Textbook of wood technology: Structure, identification, properties, and uses of the commercial woods of the United States and Canada*, (4th Ed.). New York, USA: Mc Graw-Hill Book Company.

RI has the opportunities to take over the paper market (in Bahasa Indonesia). (2012). *Koran Jakarta, May 30*. Retrieved from http://koran-jakarta.com/index.php/detail/view01/92110

Sable, I., Grinfeld, U., Jansons, A., Vikele, L., Irbe, I., Verovkins, A., & Treimanis, A. (2012). Comparison of the properties of wood and pulp fibers from lodgepole pine (*Pinuscontarta*) and scots pine (*Pinus sylvestris*). *Bio Resources*, *7*(2), 1771–1783.

Silitonga, T., Siagian, R., & Nurahman, A. (1972). Wood fiber measurement method in forest products research institute (Special Publication of Forest Products Research Institute) (in Bahasa Indonesia). Bogor: Direktorat Jenderal Kehutanan Departemen Pertanian.

Smook, G.A. (1997). *Handbook for pulp & paper technologists*. Vancouver: Angus Wilde Publications.

Soemitro, A. (2004). Economic Financial Analysis and Investation Prospect of Plantation Forest. In E. B. Hardiyanto & H. Arisman (Eds.), *Development of Acacia mangium Plantation Forest: an Experience in PT Musi Hutan Persada, South Sumatra (in Bahasa Indonesia)*. Yogyakarta: Polydoor Press.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., & Santas, R. (2004). Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. *Industrial Crops and Products*, *19*(3), 245–254.

LEAF AREA INDEX DERIVED FROM HEMISPHERICAL PHOTOGRAPH AND ITS CORRELATION WITH ABOVE-GROUND FOREST BIOMASS

Tyas M. Basuki[1,*]

[1]Forestry Research Institute for Watershed Management, Surakarta, Indonesia

Received: 12 April 2014, Revised: 5 March 2015, Accepted: 20 March 2015

LEAF AREA INDEX DERIVED FROM HEMISPHERICAL PHOTOGRAPH AND ITS CORRELATION WITH ABOVE-GROUND FOREST BIOMASS. Leaf area index (LAI) is one of the key physical factors in the energy exchange between terrestrial ecosystem and atmosphere. It determines the photosynthesis process to produce biomass and plays an important role in performing forest stand reflectance. Therefore building relationship between LAI and biomass from field measurements can be used to develop allometric equations for biomass estimation. This paper studies the relationship between diameter at breast height (DBH) and leaves biomass, DBH and crown biomass (sum up of leaves, twigs and branches) as well as between LAI and leaves biomass; LAI and crown biomass; LAI and Total Above-ground Biomass (TAGB) in East Kalimantan Province. Destructive sampling was conducted to develop allometric equations. The DBH measurements from 52 sample plots were used as training data for model development (35 plots) and for validation (17 plots). A hemispherical photograph was used to record LAI. The result shows that strong corelation (r) exists between natural logarithmic (*ln*) DBH and crown biomass ranging from 0.88 to 0.98. The correlation (r) between LAI and biomass of leaves; leaves + twigs + branches; TAGB were 0.742, 0.768 and 0.772, respectively. Improvement of (r) between LAI and biomass can be conducted by proper time of LAI measurement, when the sky is uniformly overcast.

Keywords: LAI, biomass, hemispherical photograph, allometric equation, East Kalimantan

INDEKS LUAS DAUN (LAI YANG DIAKSES DARI FOTO HEMISPHERICAL DAN KORELASINYA DENGAN PERMUKAAN BIOMASSA HUTAN. Indeks luas daun (LAI) merupakan salah satu faktor fisik utama dalam pertukaran energi antara ekosistem daratan dan atmosfer. LAI menentukan proses fotosintesis yang memproduksi biomassa dan berperan penting dalam reflektan parameter tegakan hutan, oleh karena itu hubungan antara LAI dan biomassa dari pengukuran lapangan perlu dibangun untuk membentuk persamaan allometrik yang selanjutnya digunakan untuk mengestimasi biomassa di tempat lain. Tulisan ini mempelajari hubungan antara diameter setinggi dada (DBH) dengan biomassa tajuk (daun; daun + ranting + cabang) dan juga antara LAI dengan biomassa tajuk; serta LAI dengan biomassa total (TAGB). Pengambilan contoh secara destruktif dilakukan untuk membangun persamaan allometrik. Pengukuran DBH dilakukan pada 52 plot di Kalimantan Timur dengan rincian 35 plot untuk membangun model dan 17 plot untuk validasi. Kamera dengan lensa mata ikan digunakan untuk mengumpulkan data LAI. Hasil penelitian menunjukkan korelasi (r) yang tinggi antara logaritmik natural (ln) DBH dengan biomassa tajuk berkisar antara 0,88 sampai 0,98. Koefisien korelasi (r) antara LAI dengan biomassa daun; tajuk (daun + ranting + cabang); dan TAGB secara berurutan adalah 0,742, 0,768, dan 0,772. Peningkatan koefisien determinasi hubungan antara LAI dengan biomassa dapat ditingkatkan melalui pengukuran LAI pada waktu yang tepat yaitu kondisi langit seragam dan tidak terlalu cerah.

Kata kunci: LAI, biomasa, kamera berlensa mata ikan, persamaan alometrik, Kalimantan Timur

[*]Corresponding author: tmbasuki@yahoo.com

I. INTRODUCTION

The method of estimating carbon can be grouped into two approaches, i.e., direct and indirect measurements. Harvesting and weighing the tree biomass is considered as a direct measurement, while indirect method or non-contact method can be conducted through satellite or airborne remote sensing (Basuki, Skidmore, van Laake, van Duren & Hussin, 2012; Basuki, Skidmore, Hussin & van Duren, 2013) as well as using hemispherical photography (Riaño, Valladares, Condés & Chuvieco, 2004). The direct measurement is considered the more accurate than the non-contact method however it is time consuming and costly (Wang, Hall, Scatena, Fetcher & Wu, 2003). The direct measurement commonly is used to validate the result obtained from indirect measurement. The biomass measurements using remote sensing techniques need more expertise on image analysis, which may cover areas from landscape level to global level (Rosenqvist, Milne, Lucas, Imhoff & Dobson, 2003).

The non-contact method using hemispherical photograph or fisheye lens has been applied to estimate Leaf Area Index (LAI) and biomass by previous studies (Beckschäfer, Fehrmann, Harrison, Xu & Kleinn, 2014; Gonsamo & Pellika, 2008; Hanssen & Solberg, 2007; Thimonier, Sedivy & Schleppi, 2010). This device produces a continuous two dimensional spatial record of the canopy structure (Silbernagel & Moeur, 2001). It can also be used to assess canopy openness, LAI and light transmittance (Hale & Edwards, 2001). LAI assessment using hemispherical photograph is considered as tedious, however it can be used as validation for LAI measurement using satellite imageries (Morsdorf, Kötz, Meier, Itten & Allgöwer, 2006; Sea, Cholerb, Beringerc, Weinmannd, Hutleyd & Leuninga, 2011).

The estimation of tree biomass using the non-contact method can be performed by developing relationship between forest stand variables, such as leaf area index (LAI), diameter at breast height (DBH), crown cover, and tree height from field measurements. In this method, the reflectances of the foliage or crown closure of forests were captured by the sensors which indirectly measured the required parameters and biomass. In the case of using hemispherical photograph, the basic concept of the work is that the quantity and distribution of understory light are mainly affected by the number, size, and location of gaps in forest canopies (Frazer, Canham & Lertzman, 1999). During the measurement the camera position was skyward, taken from forest floor with a 180° fisheyes lens producing circular images which recorded the forest overstory condition (Frazer et al., 1999). Afterwards, the camera converted the images into bitmaps and the images were analyzed using a software, such as Gap Light Analyzer or GLA (Frazer et al., 1999).

LAI in broadleaf forest is defined as one sided green leaf area per unit ground area (Olivas et al., 2013; Pu, Yu, Gong & Biging, 2005) and it is the key physical factor in the energy exchange between terrestrial ecosystem and atmosphere (Cristiano, Klein, Niklaus & Kuenzer, 2014; Gonsamo & Pellikka, 2008). The LAI also plays an important role in stimulating carbon and hydrological cycles (Beckschäfer et al., 2014; Olivas et al., 2013). In photosynthesis process, LAI is the driving factor to produce biomass or net primary production (Eisfelder, Klein, Niklaus & Kuenzer, 2014). LAI also influences reflectance performances of forests (Ollinger, 2010), therefore LAI influences the physiological process and the performance of the forests.

Developing regression models between LAI and forest parameters has been carried out intensively, especially using satellite imagery. Caldararu, Palmer and Purves (2012) have assessed spatial and temporal LAI from MODIS (Moderate Resolution Imaging Spectroradiometer) imagery in tropical forest in the Eastern and Shuthern Amazon. While, Samanta et al. (2012) has studied seasonal changes of LAI in savannah and forest also in the Amazon area. In addition, Spracklen et al. (2012) have observed the correlation between precipitation and LAI derived from MODIS data. Morsdorf et al. (2006) assessed LAI using airborne laser scanning (Light Detection and

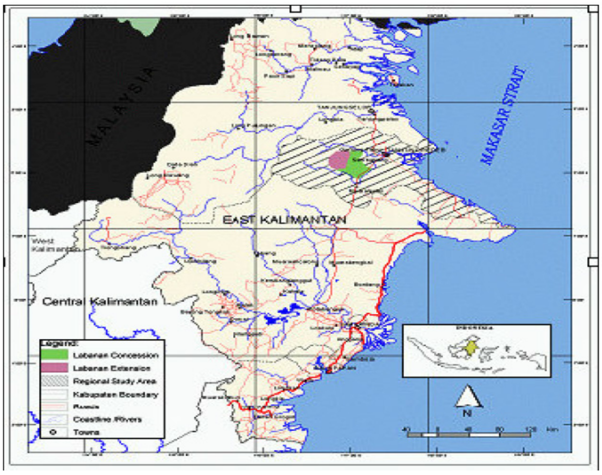

Figure 1. The situation map of the study area
Source: Wahyuningrum (2006)

Ranging or LIDAR) in pine-dominated forest, while Riaño et al. (2004) compared measurement of LAI by LIDAR and hemispherical photos in broad leave forest. Based on reviewed literatures, many of the studies to assess LAI were conducted in tropical Amazonian and boreal forests. In Indonesia LAI measurement was conducted by Dietz, Hölscher, Leuschner, Malik and Amir (2007) at Montana forests in Central Sulawesi. Therefore research to measure LAI in dipterocarp forests was necessary because these forests cover large areas and they are one of the most commercialized hard wood species from South-East Asia (Basuki, van Laake, Skidmore & Hussin, 2009).

The objective of the study was to obtain information of relationship between LAI and above-ground biomass in dipterocarp forest. This intended examination creates models that also can be useful for estimating biomass in other places having similar characteristics and may be for validating LAI measurements using other methods such as remote sensing techniques which is derived from Moderate Resolution Imaging Spectroradiometric (MODIS) LAI product.

II. MATERIAL AND METHOD

A. The Study Area

The study was undertaken in the Labanan forest concession area which is dominated by dipterocarp tree families with common genera of Shorea, Dipterocarpus and Vatica. The area lies between latitude 2°11’ and 2°20’ North and longitude from 116°55’ to 117°20’ East. Administratively, this concession belongs to Berau Regency, East Kalimantan Province. The map of the study area is presented in Figure 1.

B. Data Collection

Field measurements consisted of two steps, i.e. destructive sampling of tree samples (122 trees from 48 species) to develop allometric equations and forest inventory in each determined sample plot. The whole aboveground biomass except root was considered as Total Above Ground Biomass (TAGB). As explained in Basuki et al. (2009), detailed explanation of destructive sampling was conducted by separation of tree components into leaves, twigs, branches, and stem. The stems and big branches were cut in 2 m sections and the volume was computed. Samples were collected for every tree component and dried in laboratory to obtain moisture content. The moisture content was used to convert the fresh weight into dry weight for each tree component and summed up to obtain dry weight for the whole tree except for the root.

The allometric equation to estimate the TAGB was based on Basuki et al. (2009) namely:

$$\ln(TAGB) = 2.196*\ln(DBH) - 1.201$$

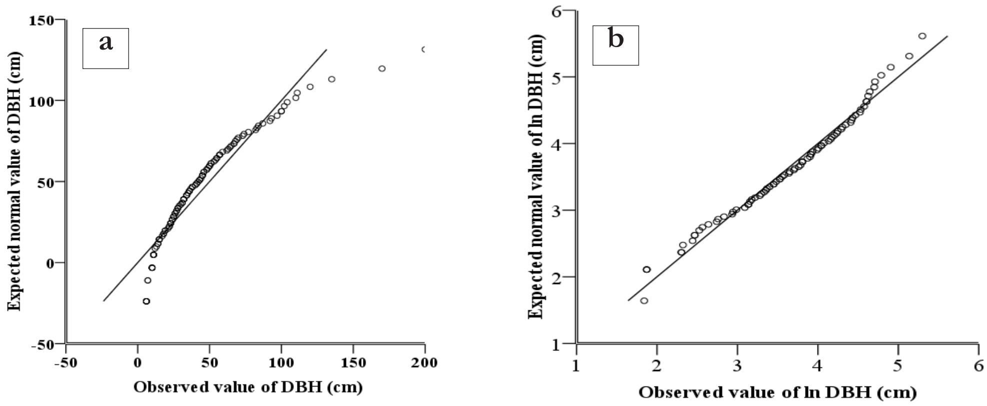

Figure 2. Distribution of DBH (cm) before (a) and after transformation (b)

where: TAGB is the total above-ground biomass in dry weight (kg/tree), DBH is in cm, the adjusted R^2 of the model is 0.963.

There were 52 sample plots which were distributed randomly in the study area. The size of the plot was 500 m^2 in a circular shape. The radius of the plot depends on the slope of the terrain. All trees with a diameter equal or greater than 10 cm were measured using a diameter tape. Thirty five (35) plots were used for developing regression models and seventeen (17) plots were used for validation.

The LAI for every plot was measured using hemispherical photograph. This photograph has a 1800 field of view. Therefore, the photo provides a circular image showing a complete view in all sky directions (Jonckheere et al., 2004). The fisheye lens with sigma 8 mm was mounted on a Nikon camera. 400 ASA color film was used to record the trees. The camera was located at the centre of the plot under the forest canopies at 1.3 m height above ground level and the lens was set upward to the forest canopies (Jonckheere et al., 2005).

C. Data Analysis

Prior to the regression analysis, normality test of the data were conducted using Q-Q plot. The results showed that the variables were not normally distributed, therefore ln transformation was conducted. Figure 2 shows distribution of DBH before (a) and after ln transformation (b).

The allometric equations consist of independent variable that is the DBH and dependent variable which is the biomass of the tree. The components of crown consists of leaves, twigs and branches. In this study, some allometric equations were developed from destructive sampling data by building relationship between DBH and dry leaves biomass; DBH and dry crown biomas, as well as DBH and the whole tree biomass except root (TAGB). Afterwards, the resulting allometric equations were used to predict biomass of leaves and crown as well as TAGB for every plot with only DBH measured. Those estimated biomasses were then integrated with a LAI value measured by hemispherical photograph in every sample plot and used to develop new allometric equations between LAI as the independent variable and dependent variables which consisted of leaves; crown; and TAGB.

The negative films of hemispherical photos were scanned and then analyzed using Gap Light Analyzer (GLA) to obtain LAI. The manual of GLA (Frazer et al., 1999) was used as a guidance to analyze the scanned films and the LAI. According to the user manual of GLA, the first procedure to compute the LAI is loading the photo, followed by image registration. The image was registered to identify two points on the circular image to get its extent and geographic orientation. Based on these two defined points, then every pixel in the image array was converted into UTM. To obtain a good performance, the saturation, brightness and contrast of the photo could be adjusted.

In this research, the pixel values of less than 172 were considered as vegetation and converted to black colour. Inversely, the rest of the pixel values having values more than or equal to 172 were assigned white colour or represented the sky condition. The last action was the running of the LAI calculation. In the GLA software, the LAI were obtained from two rings. In this study the LAI values from ring 4 were used for further analysis. The LAI data were graphed to get ideas of the relationship between the independent and dependent variables. The equations with indicators of goodness of fit (adjusted R^2) are presented in this paper.

To test the accuracy of the models, the developed allometric equations were applied to another data set which consisted of 17 plots. Afterwards, the average deviation was calculated based on Chave et al. (2005). The model with the lowest standard deviation is considered the most accurate model. The standard deviation was calculated using the formula as presented below:

$$\bar{S}(\%) = \frac{100}{n} \sum_{i=1}^{n} |\hat{Y}i - Yi| / Yi$$

where $\bar{S}$ is the average deviation, Yi = the observed dry weight, $\hat{Y}$i = the predicted dry weight, n = number of observations.

III. RESULT AND DISCUSSION

A. Relationship between leaves, crown biomass and DBH

Figure 3 shows the relationship between *ln* (DBH) and *ln* (leaves) (a), *ln* (DBH) and *ln* (crown) biomass. The results of the statistical analysis are presented in Table 1.

The coefficient of determination between DBH and leave biomasss is relatively strong in logarithmic form. The first equation consists of biomass of dry leaves and DBH, the second is crown (sum of leaves, twigs, and branches) and DBH, and the last is TAGB (sum of leaves, twigs, branches, and stem). The coefficient of determination between ln (TAGB) and *ln* (DBH) is the highest, followed by R^2 of ln (crown) and *ln* (DBH), while the lowest R^2 is of *ln* (leaves) and *ln* (DBH).

B. Relationship between LAI and biomass

The results show that in the study area, where a selective logging was applied, the LAI ranges from 1.30 to 4.28, with the mean of 2.59. For comparison, the study of Aragăo et al. (2005) in Amazon found that average LAI was 5.10 ± 0.66 in dense primary forest which was tall with closed canopy, while in logging forest it was 4.63 ± 0.12. Zhang et al. (2005) also found that LAI for Douglas-Fir stand in Vancouver Island ranged from 2.3 to 4.6 and for Black spruce ranged from 2.3 to 3.2. The variation of LAI values is affected by the species composition, the development stage of vegetation and the

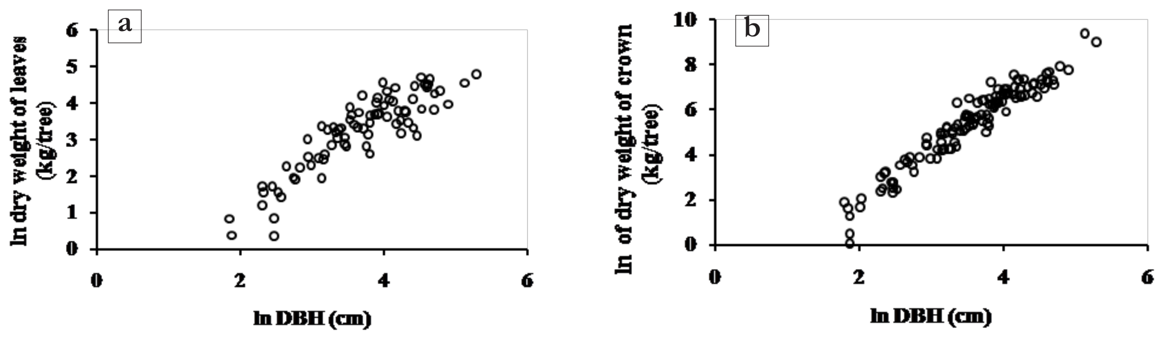

Figure 3. (a) Scatter plots of *ln* (leaves) and *ln* (DBH) and (b) *ln* (crown) and *ln* (DBH)

Table 1. Regression analysis between leaves, crown, TAGB and DBH

No.	Allometric equation	Standard error	Significance	Adjusted R^2
1.	ln (leaves) = 1.251*ln(DBH) - 1.395	0.062	p=0.000	0.77
2.	ln (crown) = 2.211*ln(DBH) - 2.445*)	0.056	p=0.000	0.93
3.	ln (TAGB)= 2.196*ln(DBH) - 1.201**)	0.039	p=0.000	0.96

Note: *) Crown consists of leaves, twigs, and branches, **) Source: Basuki et al. (2009)

Table 2. Regression analysis between leaves, crown, TAGB and DBH

No.	Allometric equation	Standard error	Significance	r	Adjusted R^2
1.	ln (leaves) = 1.612 $(LAI)^{0.084}$	0.023	p=0.000	0.743	0.538
2.	ln (crown) = 3.225 $(LAI)^{0.311}$	0.077	p=0.000	0.768	0.578
3.	ln (TAGB) = 4.230 $(LAI)^{0.261}$	0.064	p=0.000	0.772	0.584

Note: *) Crown consists of leaves, twigs, and branches, **) Source: Basuki et al. (2009)

site condition. In addition to these natural factors, Jonckheere et al. (2004) observed that management practices and methods to measure LAI influenced the results of its values.

The relationship between the LAI and the biomasses are presented in Table 2 and the scatter plots are in Figure 4. The correlation (r) between LAI and *ln* (leaves), LAI and *ln* (crown) as well as LAI and *ln* (TAGB) are around 0.75 and the coefficient of determination (R^2) ranged from 0.56 to 0.57. For comparison, the study of Dietz et al. (2007) at Montana forests in Central Sulawesi, Indonesia found that the average LAI in natural forest and forests with small timber extraction were 6.0 and 5.3, respectively. While, Khosravi, Namiranian, Ghazanfariz and Shirvani (2012) in oak forest showed that R^2 between LAI and DBH, basal area, total height and crown volume were 0.36, 0.36, 0.45, and 0.65, respectively. It was inferred that there were many sources of errors, which included the applied allometric and errors in relation to LAI assessment using hemispherical photographs. The allometric equations to estimate leaves and crown as well as total biomass were built from destructive sampling of those variables and DBH. The allometric equations have some source of error too because independent variable for leave allometric explained 77% of the dependent variable. Allometric equation for crown biomass explained 93% of the dependent variable (Table 1).

Reflectance captured by the camera could be one source of error. Based on the photo analysis, it was realized that the fisheye captured not only the foliage, but also the twigs, branches and stems (Figure 3a and 3c). Furthermore, when the threshold applied during the photo analysis to classify the image into sky and canopy cover, the twigs, branches and stems became dark (Figure 3b and 3d). However, there are still controversies on the effect of branches. Kucharick, Norman and Gower (1998) observed that the influence of branches on the estimation of LAI based on gap fraction analysis may be ignored, especially for fully leaved canopies due to the coverage of leaves. However, minor correction should be applied for the partially defoliated canopies. Figure 3 shows two types of crown conditions with the

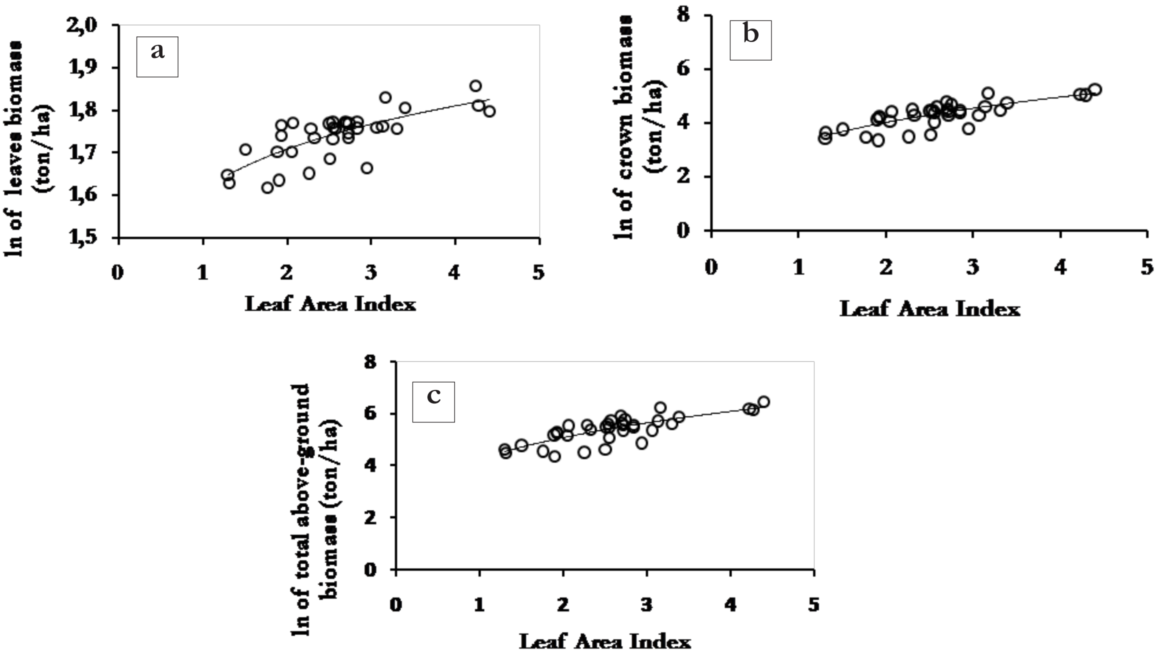

Figure 4. Scatter plots from 52 plots between *ln* (leaves) and LAI (a), *ln* (crown) and LAI (b), *ln* (total aboveground biomass or TAGB) and LAI (c)

estimated LAI being 2.55 (Figure 3a) and LAI being 1.87 (Figure 3c).

When the developed allometric equations were applied on the independent data set, the average deviation for the predicted leaves and crown biomass as well as TAGB were 4.5%, 36.7% and 38.4%, respectively. It means that the model for predicting leaves biomass is more accurate than the models for predicting crown biomass and TAGB. The sources of deviation comes from the plots that have high crown or TAGB biomass. These can be seen in Figure 4 (b and c), where the crown biomass is more than 70 ton/ha and TAGB more 200 ton/ha deviated further from 1 - 1 line than plots with crown biomass less 70 ton ha^{-1} and TAGB less than 200 ton ha^{-1}. The 1 – 1 line in Figure 4 is used to observe the distribution of the predicted values whether they are higher or lower than the measured ones. It can be seen that only the predicted values of leaves biomass are closer to the 1 – 1 (Figure 4a) and these indicate that the predicted values are closer to the actual values. Figure 4 b and c also show that the prediction are lower than the measured biomass after 70 ton ha^{-1} for crown biomass and 200 ton ha^{-1} for the TAGB, this means that the developed allometric equations are appropriate for predictions below those values.

Based on the analysis explained above, therefore LAI measurement can be applied to predict above-ground biomass in any place having the same forest condition, without direct destructive method. Assessment of LAI using hemispherical photograph is useful for validation of LAI or biomass measurement using remote sensing. Hanssen and Solberg (2007) measured strong relationship (r = 0.96) between LAI derived from airborne laser scanning and log-transformed of LAI from hemispherical photograph in pine forests. In addition, on 30 plots in conifer forest Zhao et al. (2012) measured LAI derived from a ground-based scanning LIDAR and found that the values were statistically similar to those from hemispherical photos.

To obtain an accurate estimation of LAI in secondary forest, Kalacsa, S'anchez-Azofeifa,

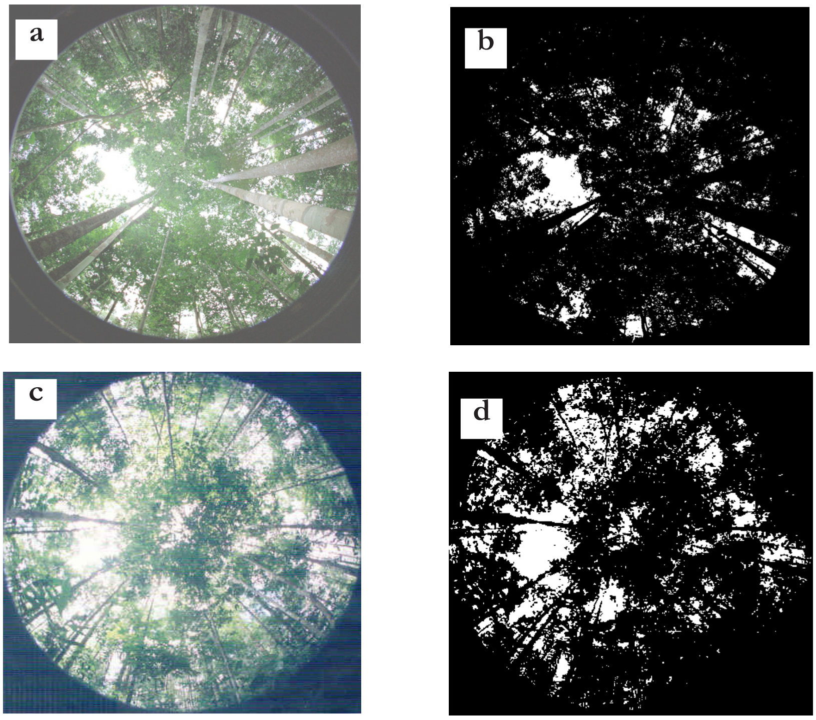

Figure 5. The crown cover captured by hemispherical photograph (a and c) and the analyzed photo after applying threshold (b and d).

Notes : The estimated LAI for Figure 5a is 2.55 and for Figure 5c is 1.87

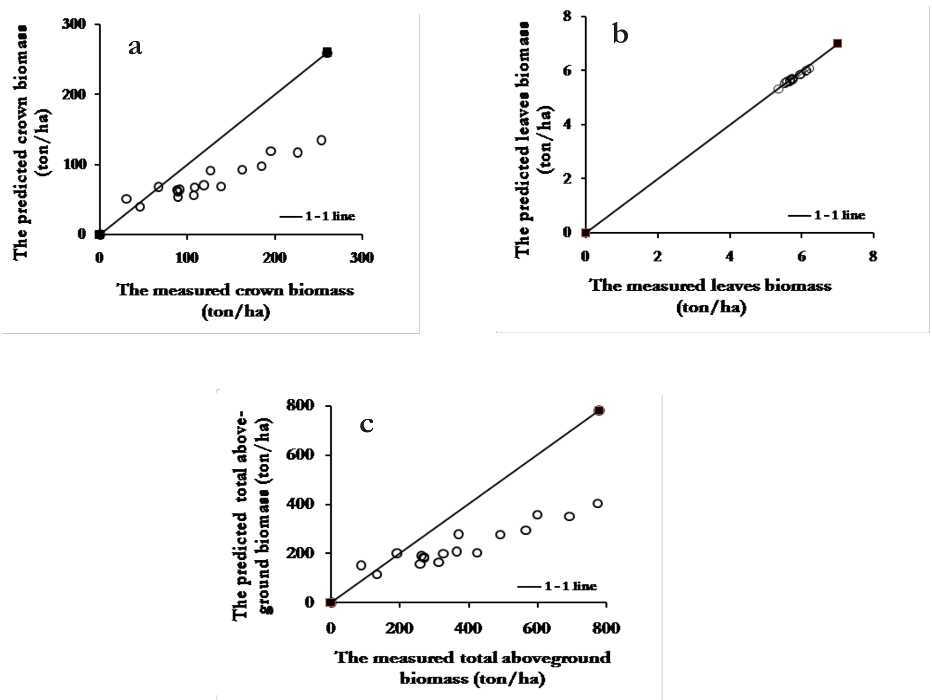

Figure 6. Distribution of the predicted leaves, crown, and total above-ground biomass around the 1 – 1 line

alvo-Alvarado, Rivard and Quesda (2005) suggested that successional stages of the forest growth should be considered. However, it is difficult to estimate LAI based on successional stages of the forests in the study area because the forests are classified as mixed forests consisting of abundant species. Besides that, the harvesting system is selective logging and the age is unkonwn, therefore the age among the trees are different and impossible to group according to successional stages.

Another way to reduce error in LAI assessment using hemispherical photograph is by considering the proper time for measurement. The measurements conducted immediately before sunrise or after sunset is a good occasion to avoid large variation of brightness across the image (Hale & Edwards, 2002). Further suggestion is by operating the photograph beneath a uniformly overcast sky (Hale & Edwards, 2002).

IV. CONCLUSION

In this study, the correlation between the LAI derived from hemispherical photograph and the aboveground biomass is relatively high, about 0.77. The developed allometric equation between LAI and TAGB have been potentially very good for estimating biomass indirectly, without doing destructive sampling, for biomass less than 200 ton ha^{-1}. The higher accuracy of LAI estimation using hemispherical photo can be obtained by a proper thresholding in differenciating the image into sky and canopy cover. The proper time of LAI measurements should be applied at a uniformly overcast sky. For further research, this study suggests to apply LAI measurement using hemispherical photographs in comparison with the estimation of LAI derived from remotely sensed data within dipterocarp forest.

ACKNOWLEDGEMENT

I would like to convey my appreciation and thanks to Bapak Ir. Dody Herika and his staffs especially mas Kirno, pak Pangut and the others for their assistance during the field campaign in the area of Labanan Forest Concession.

REFERENCES

Aragão, L.E.O.C., Shimabukuro, Y.E., Santo, F.D.B.E., & Williams, M. (2005). Landscape pattern and spatial variability of leaf area index in Eastern Amazonia. *Forest Ecology and Management*, *211*, 240–256.

Basuki, T.M., Skidmore, A.K., Hussin, Y.A., & van Duren, I. (2013). Estimating tropical forest biomass more accurately by integrating ALOS PALSAR and Landsat-7 ETM+ data. *International Journal of Remote Sensing*, *34*(13), 4871 – 4888.

Basuki, T.M., Skidmore, A.K., van Laake, P.E., van Duren, I., & Hussin, Y.A. (2012). The potential of spectral mixture analysis to improve the estimation accuracy of tropical forest biomass. *Geocarto International*, *27*(4), 329 – 345.

Basuki, T.M., van Laake, P.E., Skidmore, A.K., & Hussin, Y.A. (2009). Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. *Forest Ecology and Management*, *257*, 1684–1694.

Beckschäfer, P., Fehrmann, L., Harrison, R. D., Xu, J., & Kleinn, C. (2014). Mapping Leaf Area Index in subtropical upland ecosystems using RapidEye imagery and the random forest algorithm. *iForest*, *7*, 1–11. Retrieved from http://www.sisef.it/iforest/contents/?id=ifor0968

Caldararu, S., Palmer, P.I., & Purves, D.W. (2012). Inferring Amazon leaf demography from satellite observations of leaf area index. *Biogeosciences*, *9*, 1389–1405.

Chave, J., Andalo, A., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D. & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oceologia*, *145*, 87–99.

Cristiano, P.M., Madanes, N., Campanello, P.I., di Francescantonio, D., Rodríguez, S. A., Zhang, Y.J. & Goldstein, G. (2014). High NDVI and Potential Canopy Photosynthesis of South American Subtropical Forests despite Seasonal Changes in Leaf Area Index and Air Temperature. *Forests*, *5*(2), 287–308.

Dietz, J., Hölscher, D., Leuschner, C., Malik, A., & Amir, M.A. (2006). Rainfall partitioning in relation to forest structure in differently managed montane forest stands in Central Sulawesi, Indonesia. *Forest Ecology and Management*, *237*, 170–178.

Eisfelder, C., Klein, I., Niklaus, M., & Kuenzer, C. (2014). Net primary productivity in Kazakhstan, its spatio-temporal patterns and relation to meteorological variables. *Journal of Arid Environments*, *103*, 17–30.

Frazer, G.W., Canham, C.D., & Lertzman, K.P. (1999). *Gap Light Analyzer (GLA): Imaging software extract canopy structure and gap light transmission indices from true-colour fisheye photographs, users manual an program documentation*. New York, USA: Simon Frases University, Burnaby, British Columbia and the Institute of Ecosystem Studies, Millbrook.

Gonsamo, A., & Pellikka, P. (2008). Methodology comparison for slope correction in canopy leaf area index estimation using hemispherical photography. *Forest Ecology and Management*, *256*, 749–759.

Gower, S.T., Kucharik, C.J., & Norman, J.M. (1999). Direct and indirect estimation of leaf area index, fAPAR, and net primary production of terrestrial ecosystems. *Remote Sensing Environment*, *70*, 29–51.

Hale, S.E., & Edwards, C. (2002). Comparison of film and digital hemispherical photography across a wide range of canopy densities. *Agricultural and Forest Meteorology*, *112*, 51–56.

Hanssen, K.H., & Solberg, S. (2007). Assessment of defoliation during a pine sawfly outbreak: Calibration of airborne laser scanning data with hemispherical photograph. *Forest Ecology and Management*, *250*, 9–16.

Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M., & Baret, F. (2004). Review of methods for in situ leaf area index determination Part I. Theories, sensors and hemispherical photography. *Agricultural and Forest Meteorology*, *121*, 19–35.

Kalacska, M.E.R., S'anchez-Azofeifa, G.A., Calvo-Alvarado, J.C., Rivard, B., & Quesda, M. (2005). Effects of season and successional stage on leaf area index and spectral vegetation indices in three Mesoamerican Tropical Dry Forests. *Biotropica*, *37*(4), 486–496.

Khosravi, S., Namiranian, M., Ghazanfariz, H., & Shirvani, A. (2012). Estimation of leaf area index and assessment of its allometric equations in oak forests: Northern Zagros, Iran. *Journal of Forest Science*, *58*(3), 116 –122.

Kucharick, C. J., Norman, J. M., & Gower, S. T. (1998). Measurements of branch area and adjusting leaf area index indirect measurements. *Agricultural and Forest Meteorology*, *91*, 69–88.

Morsdorf, F., Kötz, B., Meier, E., Itten, K.I., & Allgöwer, B. (2006). Estimation of LAI and fractional cover from small footprint airborne laser scanning data based on gap fraction. *Remote Sensing of Environment*, *104*, 50–61.

Olivas, P.C., Oberbauer, S.F., Clark, D.B., Ryan, M.G., O'Brien, J.J., & Ordoñez, H. (2013). Comparison of direct and indirect methods for assessing leaf area index across a tropical rain forest landscape. *Agricultural and Forest Meteorology*, *177*, 110 – 116.

Ollinger, S.V. (2011). Sources of variability in canopy reflectance and the convergent properties of plants. *New Phytologist*, *189*, 375–394.

Pu, R., Yu, Q., Gong, P., & Biging, G. S. (2005). EO-1 Hyperion, ALI and Landsat 7 ETM+ data comaparison for estimating forest crown closure and leaf area index. *International Journal of Remote Sensing*, *26*(3), 457–474.

Riaño, D., Valladares, F., Condés, S., & Chuvieco, E. (2004). Estimation of leaf area index and covered ground from airborne laser scanner (Lidar) in two contrasting forests. *Agricultural and Forest Meteorology*, *124*, 269–275.

Rosenqvist, A., Milne, A., Lucas, R., Imhoff, M., & Dobson, C. (2003). A review of remote sensing technology in support of the Kyoto Protocol. *Environmental Science & Policy*, *6*, 441–455.

Samanta, A., Knyazikhin, Y., Xu, L., Dickinson, R. E., Fu, R., Costa, M. H., … Myneni, R. B. (2012). Seasonal changes in leaf area of Amazon forests from leaf flushing and abscission. *Journal of Geophysical Research*, *117*, 1–13.

Sea, W.B., Cholerb, P., Beringerc, J., Weinmannd, R.A., Hutleyd, L.B., & Leuninga, R. (2011). Documenting improvement in leaf area index estimates from MODIS using hemispherical photos for Australian savannas. *Agricultural and Forest Meteorology*, *151*, 1453– 1461.

Silbernagel, J., & Moeur, M. (2001). Modeling canopy openness and understorey gap patters based on image analysis and mapped tree data. *Forest Ecology and Management*, *149*, 217–233.

Spracklen, D.V., Arnold, S.R., & Taylor, C.M. (2012). Observations of increased tropical rainfall preceded by air passage over forests. *Nature*, *489*, 282 –286.

Thimonier, A., Sedivy, I., & Schleppi, P. (2010). Estimating leaf area index in different types of mature forest stands in Switzerland: a comparison of methods. *European Journal of Forest Resources*, *129*, 543–562. doi:10.1007/s10342-009-0353-8

Wahyuningrum, N. (2005). Foliage biomass estimation in tropical logged over forest East Kalimantan, Indonesia (Master Thesis) (p. 54). Enschede: ITC.

Wang, H., Hall, C.A.S., Scatena, F.N., Fetcher, N., & Wu, W. (2003). Modelling the spatial and temporal variability in climate and primary productivity across the Luquillo Mountains, Puerto Rico. *Forest Ecology and Management*, *179*, 69–94.

Zhang, Y., Chen, J.M., & Miller, J.R. (2005). Determining digital hemispherical photograph exposure for leaf area index estimation. *Agricultural and Forest Meteorology*, *133*, 166–181.

Zhao, F., Strahler, A.H., Schaaf, C.L., Yao, T., Yang, X., Wang, Z., Newnham, G. J. (2012). Measuring gap fraction, element clumping index and LAI in Sierra Forest stands using a full-waveform ground-based lidar. *Remote Sensing of Environment*, *125*, 73–79.

SOIL ORGANIC MATTER DYNAMICS UPON SECONDARY SUCCESSION IN IMPERATA GRASSLAND, EAST KALIMANTAN, INDONESIA

Ishak Yassir[1,*] and Peter Buurman[2]

[1]Natural Resoure Technology Research Institute Samboja, East Kalimantan, Indonesia
[2]Earth System Science and Climate Change Group, Wageningen University, P.O. Box 47, 6700 AA Wageningen, the Netherlands

Received: 16 March 2013, Revised: 29 March 2015, Accepted: 30 March 2015

SOIL ORGANIC MATTER DYNAMICS UPON SECONDARY SUCCESSION IN IMPERATA GRASSLAND, EAST KALIMANTAN, INDONESIA. Soil organic matter (SOM) dynamics upon secondary succession in Imperata grassland was studied by stable carbon isotope analysis. The data of litter and soil samples of twenty plots in four different stages of successions were compared. These different stages were represented by plots that were; (1) burnt 3 years before sampling/observation (Imperata grassland), (2) burnt 9 years before sampling /observation, (3) secondary forest (≥15 years) and (4) primary forest. The results showed that isotopic signatures of all soil horizons of the regeneration stages were statistically different from those of the primary forest. The A-horizon under the 3-years Imperata plot still contained 23% forest (C3) carbon, and this fraction increased to 51% in the-B-horizon. In the 9-years plot and in the secondary forest, the C3 carbon in the A-horizon increased to 51% and 96%, respectively. In the topsoil, the loss of C4-C between the 3-years and the 9-years plot was significant, while it appeared negligible in the AB-horizon. The strong decay in the topsoil under Imperata grassland may be due to the rather high carbohydrate content of the SOM, which is considered easily decomposable. Further research is needed especially to explore the relation between carbon stocks and chemical composition of SOM. Such insight may help to better understand and predict soil carbon changes in relation to climate and vegetation change.

Keywords: Carbon isotopes, Imperata grasslands, succession, soil organic matter

PERUBAHAN BAHAN ORGANIK TANAH PADA PROSES SUKSESI SEKUNDER PADA LAHAN ALANG-ALANG DI KALIMANTAN TIMUR, INDONESIA. Perubahan bahan organik tanah pada proses suksesi di lahan alang-alang telah dipelajari dengan analisis isotop karbon. Data sampel tanah dan serasah dari dua puluh petak contoh dari empat tahapan proses suksesi yang berbeda dibandingkan. Tahapan dari proses suksesi tersebut diwakili oleh petak contoh yang terdiri dari: (1) 3 tahun setelah terbakar (kondisi alang-alang), (2) 9 tahun setelah terbakar, (3) hutan sekunder (≥ 15 tahun) dan (4) hutan primer. Hasil menunjukkan bahwa isotop karbon dari semua horizon tanah pada setiap tahapan regenerasi, secara statistik berbeda dengan isotop karbon dari hutan primer. Di Horizon-A pada petak contoh 3 tahun setelah terbakar masih berisi karbon C3 23%, dan fraksi ini meningkat menjadi 51% di horizon-B. Di petak contoh 9 tahun setelah terbakar dan di hutan sekunder, karbon C3 di horizon-A meningkat masing-masing menjadi 51% dan 96%. Di lapisan atas tanah (topsoil), hilangnya karbon C4 antara petak contoh 3 dan 9 tahun terjadi secara signifikan, akan tetapi tidak di horizon-AB. Pembusukan yang terjadi sangat cepat di lapisan tanah pada lahan alang-alang, kemungkinan disebabkan kandungan karbohidrat yang cukup tinggi dari bahan organik, yang dianggap mudah terurai. Penelitian lebih lanjut diperlukan terutama untuk menggali hubungan antara stok karbon dan komposisi kimia bahan organik tanah. Pengetahuan tersebut diharapkan dapat lebih membantu untuk memahami dan memprediksi perubahan karbon tanah dalam kaitannya dengan perubahan iklim dan vegetasi.

Kata kunci: Isotop karbon, lahan alang-alang, suksesi, bahan organik tanah

---

[*] Corresponding author: ishak.yassir@gmail.com

I. INTRODUCTION

Imperata grassland is a common vegetation type in Kalimantan, Indonesia and in neighbouring parts of Southeast Asia. It indicates a high degree of degradation of the vegetation, and mostly occurs after slashing and burning of the primary forests. Through secondary succession, Imperata grassland is converted into new secondary forest and most of the original biodiversity is restored. During this succession, plant species composition and soil properties change, as discussed in previous publications (Van der Kamp, Yassir & Buurman, 2009; Yassir, Van der Kamp & Buurman, 2010). It was shown that soil carbon stocks were lower under primary forests than under Imperata grasslands in East Kalimantan and this is contrary to the situation in the other forest systems.

In order to better understand the process of succession in Imperata grassland, more should be learnt about its SOM dynamics. A common way to explore SOM dynamics in soils that have been under consecutive vegetation (succession) with a different photosynthetic pathway is by using the relative abundance of the stable isotopes ^{13}C and ^{12}C, expressed as $\delta^{13}C$ (Balesdent & Mariotti, 1996; Roscoe, Buurman, Velthorst & Pereira, 2000).

Plants with difference in photosynthetic pathway have different ^{13}C discrimination; for instance C3 are more efficient in discriminating ^{13}C than C4 plants. Therefore, C4 plants have significantly more ^{13}C in their tissue and residues than C3 plants. Plants take up carbon from the atmosphere, but ^{13}C contents in the atmosphere have changed over time, and atmospheric ^{13}C is therefore not a good reference. ^{13}C discrimination is therefore expressed with respect to a geological standard, the PeeDee belemnite, or its gas equivalent (Vienna-PeeDee). The discrimination is expressed as $\delta^{13}C$ and calculated as $\delta^{13}C$ (per mil) = $1000 * (^{13}R_{sample} - ^{13}R_{standard}) / ^{13}R_{standard}$, in which ^{13}R is the $^{13}C/^{12}C$ ratio. Plants with a C3 photosynthetic pathway have $\delta^{13}C$ values ranging from -32 to -22 $^{0}/_{00}$ (mean of -27$^{0}/_{00}$), and C4 plants have $\delta^{13}C$ values of -16 to -9$^{0}/_{00}$ (mean of -130/00), while the present $\delta^{13}C$ value in the atmosphere is -8$^{0}/_{00}$ (Boutton, 1996; Balesdent & Mariotti, 1996; Roscoe et al., 2000). Plant litter and the SOM derived from it, inherits the ^{13}C signature of the living plant. Hence, the isotopic signature of SOM can be used to explore its dynamics, when C4 plants are replaced by C3 plants or vice-versa. As Imperata is a C4 grass, the contribution of Imperata-derived SOM and its disappearance upon secondary succession, as well as the new input of C3 SOM from trees and shrubs, can be studied this way.

$\delta^{13}C$ values have been used and analysed in many studies on SOM dynamics in a variety of vegetation and land use types, including tropical ones (Boutton, Archer, Midwood, Zitzer & Bol, 1989; Vitorello, Cerri, Andreux, Feller & Victoria, 1989; Martin, Mariotti, Balesdent, Lavelle & Vuattoux, 1990; Veldkamp, 1994; Roscoe et al., 2000; Magnusson et al., 2002; Qiming, Shijie, Hechun & Ziyuan, 2003; Wilcke & Lilienfein, 2004; Marin-Spiotta, Silver, Swanston & Ostertag, 2009; Katsuno, Miyairi, Tamura, Matsuzaki & Fukuda, 2010). Nevertheless, such studies have not been carried out on the effect of a conversion of forests into Imperata grasslands or the succession from Imperata grassland to secondary forest. So far in Indonesia, most of the studies on *Imperata* grasslands focussed on soil carbon stocks changes in relation to changing land use (Van Noordwijk, Cerri, Woomer, Nugroho & Bernoux, 1997; Lal & Kimble, 2000; Woomer et al., 2000; Ohta, Morisada, Tanaka, Kiyono & Effendi, 2000; Van der Kamp et al., 2009; Yonekura et al., 2010).

The present study describes SOM dynamics upon secondary succession in Imperata grassland using stable carbon isotopes. The data of litter and soil samples of twenty plots in four different stages of succession were compared. We compared the effect of succession on proportions and absolute amounts of C3- and C4-derived SOM in order to determine differences in accumulation and decay. Such information may indicate why carbon stocks

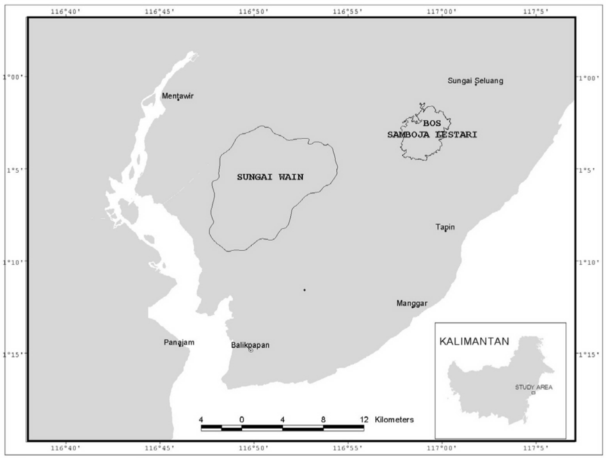

Figure 1. Location of Sungai Wain protection forest and BOS Samboja Lestari

under primary forest are lower than under Imperata grassland.

II. MATERIAL AND METHOD

A. Study Area

The study areas Sungai Wain and BOS Samboja Lestari are situated in East Kalimantan, Indonesia (Figure 1). Sungai Wain is a unique protected forest of about 10,000 hectares that contains one of the last primary forests of the Balikpapan – Samarinda area (Whitehouse & Mulyana, 2004). Samboja Lestari is a 1,850 hectares reforestation project owned by the Borneo Orang-utan Survival Foundation (BOS). Plots selected for the analysis of the regeneration impacts were situated at Samboja Lestari, whereas the primary forest plots were chosen in the area of Sungai Wain and functioned as controls. The Köppen system classifies the climate of the research area as Af (Tropical Rainforest). Average annual precipitation is 2,250 mm. The daily maximum temperature varies from 23°C to 31°C and the relative humidity is high. The soil in both areas, Samboja Lestari and Sungai Wain, is formed on marine sediments and it is classified as Acrisol according to the FAO classification system (FAO, 2001). This soil has a low level of nutrients, especially that of available phosphorus. Its pH value varies between 4.09 and 4.55 (Yassir & Omon, 2006).

B. Data Collection and Analysis

All field data and soil samples were collected in the areas of Samboja Lestari and Sungai Wain. The classification of the plots in Samboja Lestari was based on the fire history and previous studies (Van der Kamp et al., 2009). The general descriptions of the soil properties and vegetation dominances in each of the sample plots are summarized in Table 1.

In total, twenty plots of 2 m x 2 m were analysed, representing four different stages of successions. Five plots were sampled in each stage. The defined stages were found in using plot areas that were burnt 3 years and 9 years before sampling, a secondary forest of at least 15 years growth, and a primary forest. Logging in the area started around 1970 and was followed by continued slashing and burning. In 1982 to 1983 after droughts and forest fires, induced by the El Nino Southern Oscillation (ENSO) event, the area was fully covered by Imperata grassland, which was burnt again virtually every year afterwards, except in the protected area of Samboja Lestari. When the 3-years plots were sampled in 2007, there were about 25 years of decay of the C3 SOM in these plots. Soil samples were taken from the A-, AB- and B-horizons, except under the primary forest where AB-horizons were lacking. After drying and mixing, the soil was sieved over a 2 mm sieve and packed in smaller labelled bags for transport to

Table 1. Soil properties and dominant species in sampled plots

Regeneration Stage	Means							Dominant species
	Bd[a)] (g cm^{-3})	pH	C (g kg^{-1})	N (g kg^{-1})	C/N	P (mg kg^{-1})	K (cmol^{+} kg^{-1})	
3 years (n=47)								
A-horizon	1.18	5.29	14.52	1.43	10.53	4.04	0.16	*Imperata cylindrica*
AB-horizon	1.32		8.99					*Eupatorium inulaefolium*
B-horizon	1.38		3.75			3.16	0.11	
9 years (n=126)								
A-horizon	1.10	5.09	15.96	1.54	10.36	4.47	0.16	*Melastoma malabathricum*
AB-horizon	1.34		9.10					*Eupatorium inulaefolium*
B-horizon	1.39		3.99			3.72	0.11	*Vernonia arborea* etc.
Secondary forest (> 15 years) (n=43)								
A-horizon	1.10	5.11	16.71	1.58	10.58	4.08	0.18	*Syzigium lineatum*
AB-horizon	1.32		8.93					*Fordia splendidissima*
B-horizon	1.41		4.04			3.60	0.10	*Pternandra azurea*
								Macaranga sp.
								Vernonia arborea
								Vitex pinnata etc.
Primary forest (n=28)								
A-horizon	1.2	4.82	14.33	1.19	12.04	5.31	0.11	*Shorea* sp.
AB-horizon								*Madhuca* sp.
B-horizon	1.43		3.43			7.27	0.13	*Macaranga* sp.
								Syzigium sp.
								Gironniera sp. etc.

Note: *) Bda) = bulk density

the laboratory in Bogor Agricultural University (Java) for some soil chemical properties and to the laboratory in the University of California at Davis for stable carbon isotope analysis.

As the $\delta^{13}C$ value of any soil sample is a linear mixture of the contributions of the vegetation dominated by C_3 and C_4 plants, the relative contribution of each can be calculated from $\delta^{13}C_{sample} = x * \delta^{13}C_{C3} + (1-x) * \delta 13C_{C4})$, in which x is the fraction of C_3-derived, and (1-x) the fraction of C_4-derived soil organic carbon, while the $\delta^{13}C$ values denote the typical means of the relevant C_3 and C_4 litter. Data were analysed using SPSS. Least Significant Difference (LSD) tests were performed to determine statistically significant differences between $\delta^{13}C$ values of the various stages of succession.

III. RESULT AND DISCUSSION

A. Soil Properties and Vegetation in Different Phases of Regeneration

In our case study, carbon and nitrogen content in the A-horizon showed a small increase with regeneration stage, but C and N contents decreased in the primary forest (Table

Table 2. Means of δ^{13C} parameters in litter and soil samples following the different phases of successions

Descriptions	3 years (n=5)		9 years (n=5)		Secondary forest (n=5)		Primary forest (n=5)	
	Mean	sd[1]	Mean[2]	sd	Mean	sd	Mean	sd
Litters								
$\delta^{13}C$ ($^0/_{00}$)	-19.83[a]	3.75	-27.72[b]	0.83	-29.91[bc]	0.67	-31.07[c]	0.32
A-horizon (0-10 cm)								
$\delta^{13}C$ ($^0/_{00}$)	-22.14[a]	1.00	-25.09[b]	1.11	-28.19[c]	0.84	-29.86[d]	0.33
AB-horizon (10-18 cm)								
$\delta^{13}C$ ($^0/_{00}$)	-23.00[a]	0.75	-25.12[b]	1.16	-27.63[c]	0.55		
B-horizon (18-45 cm)								
$\delta^{13}C$ ($^0/_{00}$)	-24.54[a]	0.43	-26.09[b]	0.68	-27.30[c]	0.52	-29.14[d]	0.24

Note: [1]*Standard deviation,* [2]*Means followed by different letters within one soil parameter differ significantly ($P<0.05$) as established by the LSD- test*

1). The plots of the primary forest showed low N content, which was also reflected in a higher C/N ratio than in the other plots. The pH of the A-horizon was highest in the Imperata grassland and lowest in the primary forest samples. When the vegetation was reduced to ashes through burning, as happened in the grassland plots, the pH increased due to the formation of carbonates. With time, the carbonates were leached and exchangeable cations (especially calcium) were lost, resulting in a decline of the pH (Binkley, Valentine, Wells & Valentine, 1989; Cruz & del Castillo, 2005; Farley, Pineiro, Palmer, Jobbagy & Jackson, 2008; Yamashita, Ohta & Hardjono, 2008). The P of the A-horizon was also lowest in the Imperata grassland and highest in the primary forest samples. The increase in P content in the soil is not surprising, because this nutrient is mostly induced by plant inputs under vegetation succession from Imperata grassland to primary forest (Vitousek, 1984; Yassir et al., 2010). The P increase with regeneration may be also attributable to Arbuscular mycorrhiza fungi. For instance, some pioneers such as *Melastoma malabathricum*, *Vitex pinnata*, *Vernonia arborea*, *Ficus* sp. plants are dependent and associated with Arbuscular mycorrhiza fungi (Yassir & Omon, 2006). Table 1 also indicates vegetation structure and floral composition change under vegetation succession from Imperata grassland to primary forest. Grasslands dominated by *Imperata cylindrica* were replaced by shrubs and young growth of trees. In the plots that were burnt 3 years and 9 years before sampling, *Melastoma malabathricum*, *Eupatorium inulaefolium*, *Ficus* sp. and *Vitex pinnata* became the dominant species, but these species were rarely found in the secondary forest. More detailed information related to Table 1 is described by Van der Kamp et al. (2009) and Yassir et al. (2010).

B. $\delta^{13}C$ Signature

Table 2 indicates that the ^{13}C signatures of the four litters are significantly different. This difference is reflected in the signatures of the soil horizons, which reflect the differences of the litters. The largest difference is between the

Table 3. Means and standard deviations of the C3 carbon fraction in soils under various succession stages

Depth	C-fraction from C3 [1)]					
	3 years (n=5)		9 years (n=5)		Secondary forest (n=5)	
	Mean	Sd [2)]	Mean [3)]	Sd	Mean	Sd
A-horizon (0-10 cm)	0.23[a]	0.10	0.51[b]	0.19	0.96[c]	0.09
AB-horizon (10-18 cm)	0.31[a]	0.07	0.43[a]	0.23	0.93[b]	0.10
B-horizon (18-45 cm)	0.51[a]	0.04	0.47[a]	0.20	0.82[b]	0.15

Note: [1)] *Imperata grassland fraction; 2) Standard deviation; 3) Means followed by different letters within one soil parameter differ significantly (P<0.05) between regeneration stages as established by the LSD- test*

3-years plots and the other stages. In general the mean $\delta^{13}C$ value of the litter samples from the Imperata grassland plots ($-19.83^0/_{00}$) was lower than that of C_4 plants ($-13^0/_{00}$). These low values reflect that the grasslands, in addition to *Imperata*, also contain the C_3 plants *Eupatorium inulaefolium* and *Melastoma malabathricum*. The common occurrence of these C_3 species and their variations in abundance explains the exceptionally high variability (standard deviation = 3.75) of the $\delta^{13}C$ value in the 3-years litter samples compared to the other plots (Table 2).

In all the plots, the $\delta^{13}C$ value increased gradually with soil depth (Table 2). It also increased from litter to topsoil (A-horizon) except in the 3-years plot. The causes for an increase with depth of $\delta^{13}C$ values that have not undergone a C3-C4 change have been discussed in detail by other authors (Nadelhoffer & Fry 1988; Martin, Mariotti, Balesdent, Lavelle & Vuattoux, 1990; Ehleringer, Buchmann & Flanagan, 2000; Balesdent, Girardin & Mariotti, 1993; Balesdent & Mariotti, 1996; Roscoe et al., 2000; Garten, Hanson, Todd, Lu & Brice, 2007; Chen et al., 2008). As selective decay, which has been suggested as a cause, would result in relative accumulation of 13C-depleted compounds such as aromatic and aliphatic (Boutton, 1996), this cannot be an explanation. We consider the decay of primary plant material and the admixture of microbial SOM as the most likely cause, as microbial matter has higher $\delta^{13}C$ values than the corresponding SOM (Dijkstra et al., 2006).

C. C4-C3 Replacement During the Succession

The vegetation sequence started with primary forest, which was followed – through logging and slashing and burning – by Imperata grassland. The latter was in turn replaced by shrubs and trees. To calculate the remaining forest C in the 3-years plot, we used the mean values of the $\delta^{13}C$ soil samples under primary forest for the initial stage, and the $\delta^{13}C$ of the 3-years litter to calculate the relative contribution of the Imperata and the forest SOM. This implies that the 'Imperata contribution' includes that of the C3 plants in that vegetation. No correction was applied for a possible increase in $\delta^{13}C$ signature from Imperata litter to SOM.

Table 3 shows that the fractions of C3 carbon (thus of C4 carbon) in the A-horizon were significantly different in the three regeneration stages. In the deeper horizons, there is no significant difference between the 3-years and the 9-years stage. The 3-years stage retained 23% of forest C in the topsoil, which increased to 51% in the B-horizon. The 9-years stage showed a significant increase in the C3

Table 4. The means and standard deviations of absolute amounts of C3 and C4 carbon in the various succession stages

Depth	C4)[1] (g kg^{-1})						C3)[2] (g kg^{-1})					
	3 years (n=5)		9 years (n=5)		Secondary forest (n=5)		3 years (n=5)		9 years (n=5)		Secondary forest (n=5)	
	Mean	Sd)[3]	Mean)[4]	Sd	Mean	Sd	Mean	Sd	Mean	Sd	Mean	Sd
A-horizon (0-10 cm)	12.10[a]	2.83	7.18[b]	2.77	0.77[c]	1.02	3.56[c]	1.45	8.32[b]	4.18	17.64[a]	7.79
AB-horizon (10-18 cm)	6.52[a]	1.45	5.96[a]	2.62	1.03[b]	0.82	2.92[b]	0.72	4.50[b]	2.34	8.98[a]	3.04
B-horizon (18-45 cm)	2.06[a]	0.66	2.44[a]	1.16	1.03[a]	0.73	2.14[a]	0.92	2.02[a]	0.73	3.28[a]	0.99

Note: *[1)] Absolute amounts of C from Imperata grassland; 2) absolute amounts of C from primary forest; 3) Standard deviation; 4) Means followed by different letters within one soil parameter differ significantly (P<0.05) between regeneration stages as established by the LSD- test*

Table 5. Factors determining carbon stocks in East Kalimantan

Imperata grassland	Secondary forest	Primary forest
Seasonally high temperature	Temperature maxima decreasing with time	Moderate temperature
Seasonally low moisture	Moisture deficit decreasing with time	Permanent moisture
High root litter production	High litter production	Moderate litter deposition
Less efficient SOM decay	Increasingly efficient SOM decay	Efficient SOM decay
Higher carbon stocks	Carbon stock first increases further and then decreases when primary forest equilibrium is regained	Low carbon stocks

fraction in the A-horizon, but not in the deeper horizons. The secondary forest had the highest C3-C fractions (82-96%) in all horizons. In the 9-years plot, the increase in C3-C is due to (1) input of the C3-plants (*Melastoma malabathricum*, *Eupatorium inulaefolium* and *Vernonia arborea*), and (2) loss of the C4 fraction through decomposition. The further increase in C3-C fraction from the 9-years plot to the secondary forest is due to the different set of C3 species (*Syzigium lineatum*, *Fordia splendidissima*, *Pternandra azurea*, *Macaranga* sp., *Vernonia arborea*, *Vitex pinnata*), and to further decay of the C4-C fraction. To distinguish between the effects of accumulation and decay, we will consider the absolute amounts of C3- and C4-derived carbon. Table 4 shows that the absolute amounts of C4 and C3-carbon in the A-horizons differ significantly between all plots. The amount of C4-C decreased from 12.1 to 7.18 g kg^{-1} between the 3-and 9-years plots, while the secondary forest had only 0.77 g kg^{-1}. For the AB-horizon, there was a significant difference between the secondary forest and the other two stages, while no significant differences in quantities were found in the B-horizons. Figure 2 depicts the absolute amounts of C3 and C4 carbon in the three succession stages, while in Figure 2A also the contents of the primary forest are included.

Figure 2 shows that under secondary forest, the absolute amount of C4 carbon was very low throughout. Considering that there was no significant decrease in C4-C in the AB-horizon from the 3-years to the 9-years plot, it

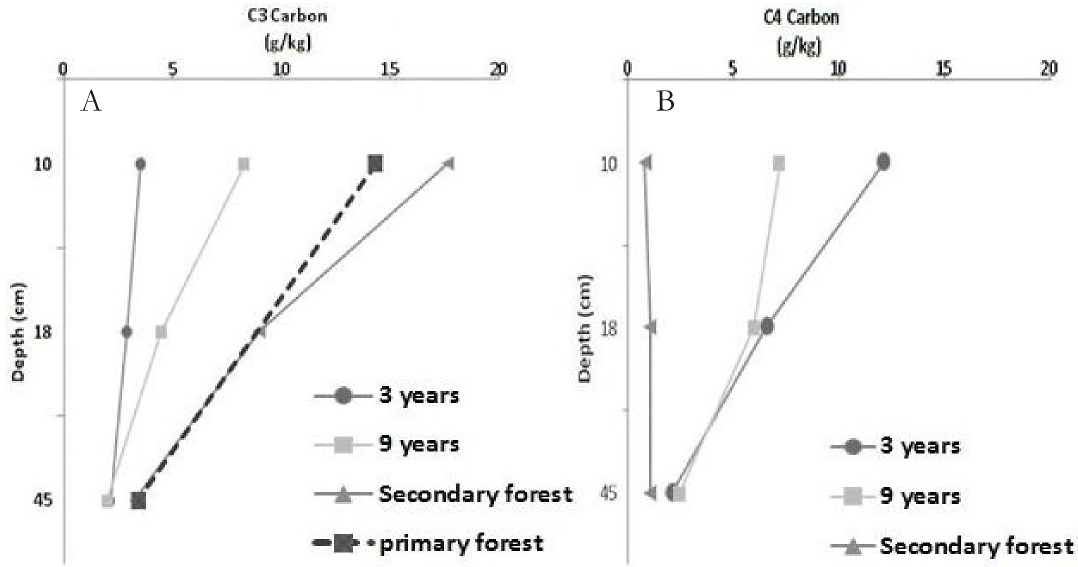

Figure 2. Location of Sungai Wain protection forest and BOS Samboja Lestari

is unlikely that decay could explain the very low contents of C4-C in the secondary forest plot. It is therefore likely, that the secondary forest plot represented a regeneration of the primary forest after logging and burning, but without a significant Imperata phase. This implies that the secondary forest plot cannot be used to estimate decay of C4-C. In that case, the calculated (low) C4-C contributions in the soil under secondary forest are due to the choice of parameters ($\delta^{13}C$ of Imperata grassland and secondary forest litter) rather than to actual Imperata input.

Figure 2b and Table 4 indicate that the loss of C4-C in the topsoil between the 3- years and the 9-years plot is considerable, while it appears negligible in the AB-horizon. The decay of C4-C in the topsoil amounted to approximately 4.92 g kg-1 in approximately 6 years or a decay rate of C4-C of 0.82 g C kg^{-1} per year. In the primary forest, the A-horizon contained 14.33 g kg-1 C3-C, of which only 3.56 g kg-1 remained in the 3-years plot. This is a loss of 10.74 g kg^{-1} in approximately 25 years, or a decay rate of 0.43 g C kg^{-1} per year. The differences between decay rate of C4-C and C3-C in A-horizon should be associated with litter quality and substrate quality. The strong decay of C4-C in topsoil under vegetation succession indicates that C4-C (*Imperata cylindrica*) – derived SOM is more easily removed by decomposition than C3-SOM. The strong decay of C4-C in the topsoil may be due to rather high carbohydrate contents in both of the litter and soil organic matter.

However, external factors also change in response to vegetation change. Upon clearing of the forest and invasion of the Imperata vegetation, fluctuations in soil temperature will increase especially maximum temperature will be considerably higher. As a result, soil moisture will be strongly reduced during the dry season. This combined effect leads to a reduction in SOM decay because both higher temperature and lower moisture availability reduce microbial activity (Cortez, 1998; Liang, Das & McClendon, 2003; Risch, Jurgensen & Frank, 2007). During the secondary succession, the process is reversed and soil temperature and moisture gradually revert to those of the primary forest. Higher microbial activity increases the amount of soil-nitrogen and thus also stimulates decomposition. The combined effects of production and decay on soil-C stocks are summarized in Table 5.

Figure 2 also indicates that from the 3-years to the 9-years stage the increase in C3-C approximately equals the loss of C4-C. It further suggests that the differences in stock between primary forest and the three succession stages is largely due to the insertion of an AB-horizon (not present under primary forest) which, as observed in the field, has a large volume of Imperata roots. The dense root system under Imperata grassland might cause higher potential carbon storage in the soil than surface litter. The largest difference between profiles under primary forest and under Imperata grassland is the insertion of an AB-horizon under the latter. This horizon contains a large amount of roots, and Figure 2 clearly suggests that this horizon causes the increase in carbon stock. Whether the differences in carbon stocks are also related to different chemical composition of the litter input and the resulting SOM will be investigated later. Such insight may help to better understand and predict soil carbon changes in relation to climate and vegetation change.

IV. CONCLUSION

Isotopic signatures of all soil horizons of the regeneration stages were statistically different from those of the primary forest. The A-horizon under the 3-years Imperata plot still contained 23% forest (C3) carbon, and this fraction increased to 51% in the B-horizon. In the 9-years plot and in the secondary forest, the C3 carbon in the A-horizon increased to 51% and 96%, respectively. Our data show that the decay rate in the topsoil of C4-C is 0.82 g kg^{-1} C ha^{-1} per year whereas that of the primary forest is 0.43 g kg^{-1} C ha^{-1} per year. Under equal external circumstances, the differences between decay rate of C4-C and C3-C in the A-horizon should be associated with litter quality and substrate quality. Although too little information is available for further evaluation of the decomposition speed and stock changes, it is possible that the final C-stock equilibrium will not revert to that of the primary forest. Because both the removal of the forest and the maintenance of the Imperata grassland involved burning, the soils of the secondary successions should have some charcoal. As this is a very stable fraction, it is likely that soil-C equilibrium stocks under secondary forest will be somewhat higher than those under primary forest.

ACKNOWLEDGEMENT

This study was a collaboration between Wageningen University and the Indonesia Gibbon Foundation. The authors wish to thank Lukman, Suton, Asih, Andini and Idhamsyah for their support during fieldwork. We thank Badan Pengelola Hutan Lindung Sungai Wain for their permission to carry out the field research. We also thank the organisation Tropenbos-International Indonesia and especially Dr. Petrus Gunarso and Mr. Helmut Huber of Fans for Nature Germany for supporting this research. Finally, the authors wish to thank Mr E.J. Velthorst of Wageningen University for preparing our samples for the analysis at the University of California-Davis.

REFERENCES

Balesdent, J., Girardin, C., & Mariotti, A. (1993). Site related δ13C of tree leaves and soil organic matter in a temperate forest. *Ecology*, *74*, 1713–1721.

Balesdent, J., & Mariotti, A. (1996). Measurement of soil organic matter turnover using δ13C natural abundance. In T. W. Boutton & S. Yamasaki (Eds.), *Mass Spectrometry of Soils* (pp. 83–111). New York: Marcel-Dekker.

Binkley, D., Valentine, D., Wells, C., & Valentine, U. (1989). An empirical analysis of the factor contributing to 20-year decrease in soil pH in an old-field plantation of loblolly pine. *Biogeochemistry*, *8*, 39–54.

Boutton, T.W. (1996). Stable carbon isotope ratio of soil organic matter and their uses as indicators of vegetation and climate changes. In S. Boutton, T.W., Yamasaki (Ed.), *Mass spectrometry of Soils* (pp. 47–82). New York: Marcel Dekker.

Boutton, T.W., Archer, S.R., Midwood, A. J., Zitzer, S.F., & Bol, R. (1989). δ13C values of soil organic carbon and their use in documenting vegetation change in a subtropical savanna ecosystem. *Geoderma*, *85*, 5–41.

Chen, Q., Shen, C., Sun, Y., Peng, S., Yi, W., Li, Z., & Jiang, M. (2008). Soil carbon dynamics in a subtropical mountainous region, South China: Results based on carbon isotopic tracing. In H. Huang, P.M. Huang, & A. Violante (Eds.), *Soil Mineral-Microbe-Organic Interactions:Theories and Applications*. (pp. 233–258).

Cortez, J. (1998). Field decomposition of leaf litters: Relationships between decomposition rates and soil moisture, soil temperature and earthworm activity. *Soil Biol. Biochem*, *30*, 783–793.

Cruz, A.B., & del Castillo, R.F. (2005). Soil change during secondary succession in a Tropical Montane cloud forest area. *Soil Science Society of America Journal*, *69*, 906–914.

Dijkstra, P., Ishizu, A., Doucett, R., Hart, S., Schwartz, E., Menyailo, O., & Hungate, B. (2006). 13C and 15N natural abundance of the soil microbial biomass. *Soil Biology and Biochemistry*, *38*, 3257–3266.

Ehleringer, J.R., Buchmann, N., & Flanagan, L.B. (2000). Carbon isotope ratios in belowground carbon cycle process. *Ecological Applications*, *10*, 412–422.

Food and Agriculture Organization. (2001). Lecture notes on major soils of the world. In P. Driessen & J. Deckers (Eds.), *World soil resources reports - 94*. Rome, Italy.

Farley, K.A., Pineiro, G., Palmer, S.M., Jobbagy, E.G., & Jackson, R.B. (2008). Stream acidification and base cation losses with grassland afforestation. *Water Resources Research*, *44*, W00A03. doi:dx.doi.org/10.1029/2007WR006659

Garten, C.T., Hanson, P.J., Todd, D.E., Lu, B.B., & Brice, D.J. (2007). Natural 14N- and 12C-abudance as indicators of forest nitrogen status and soil carbon dynamics. In K. Michener, R., Lajtha (Ed.), *Stable isotopes in Ecology and Environmental Science* (pp. 61–82). Australia: Blackwell Publishing.

Katsuno, K., Miyairi, Y., Tamura, K., Matsuzaki, H., & Fukuda, K. (2010). A study of the carbon dynamics of Japanese grassland and forest using 14C and 13C. *Nuclear Instruments and Methods in Physics Research*, *268*, 1106–1109.

Lal, R., & Kimble, J.M. (2000). Tropical ecosystems and the global C cycle. In R. Lal, J. M. Kimble, & B. A. Stewart (Eds.), *Global Climate Change and Tropical Ecosystems* (pp. 3–32). Boca Raton: CRC Press.

Liang, C., Das, K.C., & McClendon, R.W. (2003). The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. *Bioresource Technology*, *86*, 131–137.

Magnusson, W.E., Sanaiotti, T.M., Lima, A.P., Martinelli, L.A., Victoria, R.L., C de Arau'jo, M.C., Albernaz, A. L. (2002). A comparison of δ13C ratios of surface soils in savannas and forests in Amazonia. *Journal of Biogeography, 29*, 857–863.

Marin-Spiotta, E., Silver, W.L., Swanston, C.W., & Ostertag, R. (2009). Soil organic matter dynamics during 80 years of reforestation of tropical pastures. *Global Change Biology*, *15*, 1584–1597.

Martin, A., Mariotti, A., Balesdent, J., Lavelle, P., & Vuattoux, R. (1990). Estimate of organic matter turnover rate in a savannah soil by δ13C natural abundance measurement. *Soil Biology and Biochemistry*, *22*, 517–523.

Nadelhoffer, K.L., & Fry, B. (1988). Controls on natural nitrogen-15 and carbon-13 abundances in forest soil organic matter. *Soil Science Society of America Journal*, *52*, 1633–1640.

Ohta, S., Morisada, K., Tanaka, N., Kiyono, Y., & Effendi, S. (2000). Are soil in degraded Dipterocarp forest ecosystem deteriored? A comparison Imperata Grasslands, degraded secondary forests, and primary forests. In S. Guharja, E., Fatawi, M., Sutisna, M., Ohta (Ed.), *Rain forest ecosystem of East Kalimantan: El nino, drought, fire and human impacts (Ecological Studies 140)* (pp. 49–57). Japan: Springer-Verlag.

Qiming, L., Shijie, W., Hechun, P., & Ziyuan, O. (2003). The variation of soil organic matter in a forest-cultivation sequence traced by stable carbon isotopes. *Chinese Journal of Geochemistry*, *22*, 83–88.

Risch, A.C., Jurgensen, M.F., & Frank, D.A. (2007). Effects of grazing and soil micro-climate on decomposition rates in a spatio-temporally heterogeneous grassland. *Plant Soil*, *298*, 191–201.

Roscoe, R., Buurman, P., Velthorst, E.J., & Pereira, J.A.A. (2000). Effects of fire on soil organic matter in a "cerrado sensu-stricto" from

Southeast Brazil as revealed by changes in δ13C. *Geoderma*, *95*, 141–160.

Van der Kamp, J., Yassir, I., & Buurman, P. (2009). Soil carbon changes upon secondary succession in Imperata grasslands (East Kalimantan, Indonesia). *Geoderma*, *149*, 76–83.

Van Noordwijk, M., Cerri, C., Woomer, P.L., Nugroho, K., & Bernoux, M. (1997). Soil carbon dynamic in the humic tropical forest zone. *Geoderma*, *79*, 187–225.

Veldkamp, E. (1994). Organic carbon turnover in three tropical soils under pasture after deforestation. *Soil Science Society of America Journal*, *58*, 175–180.

Vitorello, V.A., Cerri, C.C., Andreux, F., Feller, C., & Victoria, R.L. (1989). Organic matter and natural carbon-13 distribution in forest and cultivated oxisol. *Soil Science Society of America Journal*, *53*, 773–778.

Vitousek, P.M. (1984). Litterfall, nutrient cycling, and nutrient limitation in tropical forest. *Ecology*, *65*, 285–298.

Whitehouse, A.E., & Mulyana, A.A.S. (2004). Coal fires in Indonesia. *International Journal of Coal Geology*, *59*, 91–97.

Wilcke, W., & Lilienfein, J. (2004). Soil Carbon-13 Natural Abundance under Native and Managed Vegetation in Brazil. *Soil Science Society of America Journal*, *68*, 827–832.

Woomer, P. L., Palm, C. A., Alegre, J., Castilla, C., Cordeiro, D. G., Hairiah, K., Van Noordwijk, M. (2000). Slash-and-burn effects on carbon stocks in the humid tropics. In R. Lal, J. M. Kimble, & B. A. Stewart (Eds.), *Global Climate Change and Tropical Ecosystems* (pp. 99–115). Boca Raton: CRC Press.

Yamashita, N., Ohta, S., & Hardjono, A. (2008). Soil changes induced by *Acacia mangium* plantation establishment: Comparison with secondary forest and *Imperata cylindrica* grassland soils in South Sumatra, Indonesia. *Forest Ecology and Management*, *254*, 362–370.

Yassir, I., & Omon, M. (2010). The relationship between potency arbuscular mycorrhizal fungi (AMF) and soil properties in marginal land Samboja, East Kalimantan (in Bahasa Indonesia). *Jurnal Penelitian Hutan Tanaman. Pusat Penelitian dan Pengembangan Hutan Tanaman*, *3*, 107–115.

Yassir, I., Van der Kamp, J., & Buurman, P. (2010). Secondary succession after fire in Imperata grasslands of East Kalimantan, Indonesia. *Agriculture, Ecosystems and Environment*, *137*, 172–182.

Yonekura, Y., Ohta, S., Kiyono, Y., Aksa, D., Morisada, K., Tanaka, N., & Kanzaki, M. (2010). Changes in soil carbon stock after deforestation and subsequent establishment of “Imperata” grassland in the Asian humid tropic. *Plant Soil*, *329*, 495–507.

LOW CARBON DEVELOPMENT STRATEGY FOR LAND USE SECTOR IN CILIWUNG MIDDLE-STREAM WATERSHED

Gamma N.M. Sularso[1,*], Rudy P. Tambunan[2] and Andreo W. Atmoko[1]

[1]Environmental Sciences Study Program, Postgraduate Program, University of Indonesia
[2] Faculty of Geography, University of Indonesia

Received: 26 November 2013, Revised: 31 March 2015, Accepted: 1 April 2015

LOW CARBON DEVELOPMENT STRATEGY FOR LAND USE SECTOR IN CILIWUNG MIDDLE-STREAM WATERSHED. The second (2nd) and third (3rd) segment of Ciliwung middle-stream watershed land use have changed drastically over the past two decades. This paper analyses the land use change from 1989-2012 and its impact on decreasing carbon stock or increasing CO_2eq emission, as well as to establish projected Reference Level (RL) to 2020. Best RL projection was used to establish the Low Carbon Development Strategy (LCDS) in both segments. The land use changing from 1989-2012 indicated a reduction of green space area by 2,575.57 ha whereas the non-green space area increased by 2,575.57 ha. These changes decreases the carbon stock by 26,900 ton C and released CO_2eq emission by about 98,723 ton CO_2eq. Population growth, demand on land and land constraints were found to be the driving factors of land use changes in this area. Reference Level 2020 was established based on business as usual (BAU) and forward looking (FL) scenarios. The projection showed that FL was the best scenario which estimated carbon storage at 217,610 ton C in 2020. Low carbon development strategy directed to the area of green space added up to 20% carbon storage through the implementation of the strategy based on green space and non-green space which covered the areas from protection, supervision, extension or awareness and law enforcement.

Keywords: Carbon stock, Ciliwung watershed, land use, reference level

STRATEGI PEMBANGUNAN RENDAH KARBON UNTUK PENGGUNAAN LAHAN DI DAS CILIWUNG BAGIAN TENGAH. Segmen kedua dan ketiga yang merupakan bagian dari DAS Ciliwung bagian tengah mengalami perubahan penggunaan lahan yang cukup pesat selama dua dekade terakhir. Tulisan ini menganalisa trend perubahan penggunaan lahan dari 1989-2012 dan dampaknya terhadap penurunan stok karbon/peningkatan emisi CO_2*eq serta proyeksi Reference Level (RL) pada tahun 2020. Reference Level terbaik digunakan untuk membangun Strategi Pembangunan Rendah Karbon (Low Carbon Development Strategy-LCDS) di kedua segmen. Perubahan penggunaan lahan pada 1989-2012 memperlihatkan bahwa terjadi penurunan luasan ruang terbuka hijau (RTH) hingga 3.623,17 ha sedangkan non-RTH meningkat hingga 2.575,57 ha. Hal ini berdampak pada menurunnya stok karbon hingga 26.900 ton. C dan melepaskan emisi* CO_2*eq hingga 98.723 ton.* CO_2*eq. Penyebab perubahan penggunaan lahan yaitu pertambahan penduduk, kebutuhan lahan, dan keterbatasan lahan. Proyeksi RL hingga tahun 2020 dilakukan berdasarkan kondisi standar (BAU) dan rencana ke depan (FL). Hasil proyeksi memperlihatkan bahwa FL adalah skenario terbaik yang diestimasi menyimpan karbon hingga 217.610 ton C di tahun 2020. Strategi pembangunan rendah emisi karbon diarahkan pada penambahan luasan RTH hingga 20% melalui implementasi strategi didasarkan pada RTH dan non-RTH meliputi strategi perlindungan, pemantauan, penyuluhan, dan penegakan hukum.*

Kata kunci: Stok karbon, DAS Ciliwung, perubahan penggunaan lahan, reference level

---

[*] Corresponding author: gammanms@yahoo.co.id

I. INTRODUCTION

Indonesia's Green House Gasses (GHG) data from 2000-2005 showed that GHG emissions from Land Use, Land Use Change and Forestry (LULUCF) sector was 48% of total national GHG emission, with emissions in 2004 amounting to 1,415 million Gg. CO_2e (Ministry of Environment [MOE], 2010). Based on 2000-2005 data, these emissions were mainly caused by forest cover and land use changes of the area amounted approximately to 1.1 million ha/year. Land use and land cover changes in the watershed especially occurred from green space (e.g. forests, plantations, etc.) to non-vegetation area (e.g. built up area, roads, etc.), which led to decrease of carbon stock in the watershed, as well as the ability to absorb carbon. One of the watersheds that have been affected by massive land use change is Ciliwung watershed.

Ciliwung watershed is an area with a main river and tributaries located adjacently to the DKI Jakarta Province and West Java Province. Total watershed area is approximately 337 km^2 having main river length of approximately 109.7 km (MOE, 2011). Based on administrative regions, Ciliwung watershed is divided into 6 segments, spanned from upstream (1st segments), middle-stream (2nd segment, 3rd segment, and 4th segment) to downstream (5th and 6th segment), with each segment managed by the local government whose land is crossed by the Ciliwung river. The segmentation covers from Bogor Regency (2nd and 3rd segments), Bogor City (2nd segment), Depok City (4th segment) and DKI Jakarta (5th and 6th segments).

First (1st) segment and third (3rd) segment is managed by the local government of Bogor Regency, with 1st segment covering the districts of Ciawi, Cisarua and Megamendung, while the 3rd segment covers the districts of Sukaraja, Babakan Madang, Bojonggede, and Cibinong. Second (2nd) segment is managed by the local government of Bogor City, which covers the districts of South Bogor, East Bogor, Center Bogor, and Tanah Sareal. Fourth (4th) segment is managed by the local government of Depok City, which covers the districts of Bejo, Limo, Cimanggis, Sukmajaya and Pancoran Mas. Fifth (5th) segment and sixth (6th) segment is managed by the local government of DKI Jakarta Province, with 5th segment covering the districts of Jagakarsa, Pasar Minggu, Mampang Prapatan, Pancoran, Tebet, Setia Budi, Kebayoran Baru, Pasar Rebo, Ciracas, Kramat Jati, and Jatinegara, while 6th segment is covering the districts of Pulo Gadung, Matraman, Menteng, Senen, Tanah Abang, Johar Baru, Cempaka Putih, Kemayoran, Sawah Besar, Gambir, Tambora, Taman Sari, Koja, Penjaringan, Tanjung Priok, and Kelapa Gading. Ciliwung watershed segmentation can be seen in Figure 1.

This study was focused on the 2nd segment managed by the Government of Bogor City and 3rd segment managed by the Government of Bogor Regency. Second segment and third segment in Ciliwung middle-stream watershed has been affected by the land use and land cover changes during the past two decades. Increasing population and their demand for land in a limited area had become the major causes of forest/land conversion, from forests and agriculture land into built up areas (MOE, 2011). Even though up to 73% of land use in Ciliwung middle-stream was dominated by farms and plantations while the residence area increased up to 71% (Kusmana, 2003). Land use and land cover change within a catchment has provided a bad impact on the increase of soil erosion, run-off, sedimentation, micro-climate change, as well as the increase in GHG emission (Wasis, Saharjo, Arifin & Prasetyo, 2012). Land use and land cover cause the increase of built-up area in Ciliwung middle-stream which affects the quality of the watershed, especially by lower water absorption capacity and increased carbon emission.

The decreasing of green space area impact on the decreased of carbon storage in both regions. Adinugroho (2012) stated that land use pattern largely determines its carbon sequestration ability. Changes in land use must be considered in the preparation of the Regional Spatial Plan in both regions. Based on the Regional Action Plan-GHG West Java Province, the potential GHG emission absorption can be enhanced

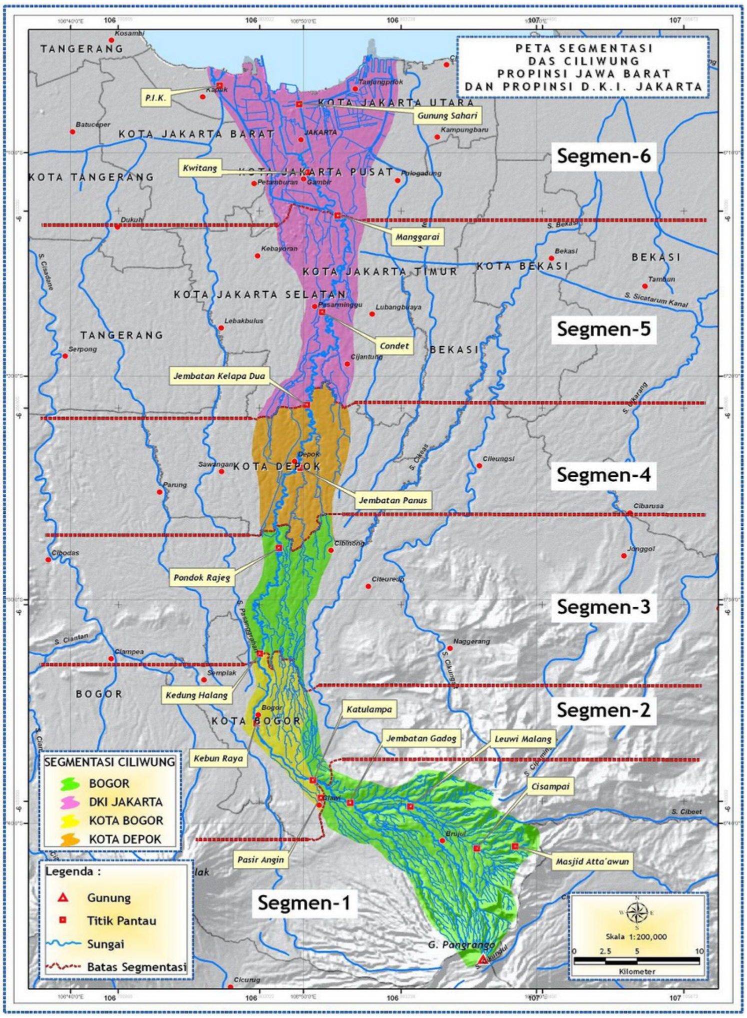

Figure 1. Ciliwung watershed segmentation map

Source : Ministry of Environment (2011)

through the increase of green space in urban areas by 30% which consists of: (1) 20% of public green space, and (2) 10% private green space located in residential areas. The creation of green space in urban areas will contribute to the national GHG emission reduction target by 2020. Government of Indonesia is targeting a national GHG emission reduction from BAU up to 26% with domestic resources and 41% with international assistance by 2020.

The objective of this study is to identify the contribution of spatial arrangement of land use and land cover on the preparation of climate change mitigation strategies for the land use sector in Ciliwung middle-stream watershed, focusing on 2nd segment Bogor City and 3rd segment Bogor Regency. The results of the study were expected to provide alternative plans that may support climate change mitigation strategies for the land use sectors in 2nd segment and 3rd segment of Ciliwung middle-stream watershed.

II. MATERIAL AND METHOD

This study was conducted in 2nd and 3rd segments of Ciliwung middle-stream watershed which is located at 60 27’07” – 60 40’47” South Latitude and 1060 47’36” – 1060 51’ 01” East Longitude. Based on administrative region, 2nd segment is located at 4 districts in Bogor City which are South Bogor, East Bogor, Center Bogor, and Tanah Sareal, while 3rd segment is

Table 1. Carbon stock average in various land use types in Ciliwung watershed

No.	Type of land use	Carbon stock average (ton C ha^{-1})
1.	Natural forest	111.20
2.	Plantation forest	144.99
3.	Mixed plantation	29.77
4.	Shrub	4.94
5.	Paddy field	4.61
6.	Dry land agriculture	4.44
7.	Built up area	2.50

Source: Wasis et al. (2012)

located at 4 districts in Bogor Regency which are Sukaraja, Babakan Madang, Bojonggede, and Cibinong. Survey and collecting Ground Control Point (GCP) were carried out in July-August 2013 to help classify land use types and areas. Sampling data consisted of land use types, population, livelihoods, carbon stock change in every type of land use, and regulations and policies related to spatial plan and regional development plan. Land use and land cover types were categorized into 9 types namely: natural forests, plantation forests, mixed plantations, dry land agriculture, paddy fields, built up area, shrubs, barren lands and water bodies.

Research data consisted of: 1) Ground Control Point (GCP) from each type of land use based on survey; 2) Landsat satellite image path/row 122/065 in 1989, 2001, and 2012 from United States Geological Survey (USGS); 3) topographic maps with a scale of 1:25,000 from Faculty of Forestry, Bogor Agricultural University which originated from Geospatial Information Agency (*Badan Informasi Geospasial*, BIG); 4) carbon stock data in Ciliwung watershed from Wasis et al. (2012); 5) spatial plan (*Rencana Tata Ruang dan Wilayah*, RTRW) and regional development plan (*Rencana Pembangunan Jangka Panjang*, RPJP) in Bogor City and Bogor Regency; 6) regulations and policies related to the study from central government and local government; and 7) statistical report of population, livelihoods, education and health facilities in Potensi Desa 1990, 2001, and 2011 from Central Statistics Agency (*Badan Pusat Statistik*, BPS).

Data analysis in this study was done through five steps. First step was identifying the trend in land use changes by supervised classification method with maximum likelihood parametric rule of Landsat TM satellite images path/row 122/65 (date of acquisition: 9 September 1989; 29 June 2001, and 27 June 2012) using ERDAS 9.1 and ArcGIS 9.3. Each image was classified with GCP of each type of land use from the survey which produced classified time series images that contained area values (ha). This result was used for analyzing land use changes from 1989 to 2012.

Second step was determining the causes of land use changes from social-economic factors based on field survey and review of document Potensi Desa (PODES) obtained from BPS. Third step was estimating carbon stock and CO_2eq emission. Calculation of carbon stock was done by multiplying land use area with carbon stock value from Wasis et al. (2012). Calculation of CO_2eq emission was done by calculating the loss of carbon stock that was caused by land conversion. The deficit of carbon stock was multiplied by 3'67 (multiplying factor to transform carbon (C) into carbon dioxide (CO_2). Reference for carbon stock data in Ciliwung watershed is presented in Table 1.

Fourth step was projection of reference level (RL) with 3 scenarios. Reference level is the

$$\text{Historic C-stock rate } \left(\frac{ton.C}{year}\right) = \text{Land use change data } \left(\frac{ha}{year}\right) \text{ x C-stock factor} \left(\frac{ton.C}{ha}\right) \quad (1)$$

$$\text{RL (ton C)} = \text{Historic carbon stock rate } \left(t\frac{ton.C}{year}\right) + \text{Sub-national circumstances} \quad (2)$$

$$\text{MA} = \frac{\sum_{i=1}^{n} activitydata}{observation\ year\ (23\ years)} \quad (3)$$

$$\text{Land use change projection} = \text{land use area in year-i (ha)} + \text{MA land use in 1989-2012 } \left(\frac{ha}{year}\right) \quad (4)$$

$$\text{RL projection} = \text{RL in year-i (ha)} + \text{MA historic carbon stock in 1989-2012 } \left(\frac{ton.C}{year}\right) \quad (5)$$

baseline of carbon storage and CO_2eq emission in the land use sector in both segments. These projections were based on historical data for business as usual (BAU) RL projection and regional policies for forward looking (FL) RL projection. Regional policy data used for determining FL RL were spatial planning regarding green space and non-green space areas obtained from the spatial plan (RTRW) and the long-term regional development plan (RPJP) regarding compliance to fulfill green space area being 30% of the total area in both regions. Formula of RL was modified based on UN-REDD in Suryadi (2012) as mentioned in equations.

Three RL scenarios were as follow: 1) BAU RL based on historical data projection without considering future spatial and regional development plans; 2) FL1 RL based on combination of historical data projection and spatial and regional development plans in a pessimistic option (built up area increases by up to 20%); and 3) FL2 RL based on combination of historical data projection and spatial and regional development plans in an optimistic option (green space area increases by up to 20%). Land use change projection from 2013 to 2020 was conducted using forecasting method of Moving Average (MA) and validated by Mean Absolute Error (MAE). Formulas of forecasting, RL and land use change projections are as follow:

Fifth step was developing Low Carbon Development Strategies (LCDS) for the land use sector, which was conducted by analyzing the best RL scenario that can increase carbon storage or reducing carbon dioxide (CO_2) emission in both segments. This strategy was modified from Low Emission Development Strategy that was developed by Dewi, Ekadinata, Galudra and Johan (2011) by focusing on developing the strategies based only on the best RL scenario that increases carbon stock in both segments. Development of implementation strategies based on spatial analysis, best RL development that support reduced CO_2 emission/increased carbon stock, and problem-solving were related to the scenario target in site.

III. RESULT AND DISCUSSION

A. Land Use Change at 2nd Segment and 3rd Segment of Ciliwung Middle-stream Watershed during 1989-2012

Based on the processed land use maps of 1989, 2001, and 2012, green space areas were identified as natural forests, plantation forests, mixed plantations, dry land agriculture, paddy fields, and shrubs, whereas non-green space areas were identified as built up areas, barren lands, and water bodies. Natural forest in both segments was mostly found along the river banks which was dominated by jackfruit (*Artocarpus heterophyllus*), gandaria (*Bouea macrophylla*) and bamboo (*Asparagus* sp., *Gigantochloa* sp., *Bambusa* sp. and *Dendrocalamus* sp.). The forest crown covered approximately 40%-70% with canopy stratification range from A to E (from emergent trees to herbs and litters). Natural forest area was largely fragmented because of land clearing and death of trees. Plantation forest in both segments was mostly found near mixed plantation, dryland agriculture and settlement. Plantation forest is dominated by teak (*Tectona grandis*) and white albizia (*Falcataria mollucana*) owned by individuals and communities as

Table 2. Land use changes in 2nd and 3rd segments of Ciliwung middle-stream watershed from 1989-2012

Type of Land Use	1989 (ha)	2001 (ha)	2012 (ha)	Land use change from 1989-2001 (ha)	Land use change from 2001-2012 (ha)
Natural forests	1,035.09	487.71	404.73	-547.38	-82.98
Plantation forests	243.72	356.4	754.65	112.68	398.25
Mixed plantations	1,493.97	622.44	452.34	-871.53	-170.1
Dry land agriculture	3,249.07	2,672.83	1,297.62	-576.24	-1,375.21
Paddy fields	82.53	207.54	259.38	125.01	51.84
Built up areas	2,786.45	3,642.22	5,264.82	855.77	1622.6
Shrubs	527.40	1,458.7	887.49	931.30	-571.21
Barren lands	2.25	0.09	152.1	-2.16	152.01
Water bodies	162.63	135.18	109.98	-27.45	-25.2
TOTAL	9,583.11	9,583.11	9,583.11		

community forest (Hutan Rakyat-HR). Most of the plantation forests were planted with spacing from 1 m x 1 m to 3 m x 3 m, but they were also interspersed with fruit trees. Mixed plantations in both segments were dominated by banana (*Musa* sp.), coconut (*Cocos nucifera*), and mango (*Mangifera indica*) which was located near dryland agriculture, forest plantation, and river banks. Dryland agricultures in both segments were dominated by cassava (*Manihot utilissima*) and chili (*Capsicum annum*) which located near settlements and roads to facilitate the transportation of the crops. Paddy fields in both segments were dominated by rice but it turned to planted crops during fallow period.

Built up area in both segments consisted of settlements from medium to compact residential, schools, offices, factories, commercial and recreational areas that were often found near river banks. Compact residential area was mostly found in 2nd segment whereas in 3rd segment it varied relatively ranging from compact residential area near the commuter train track in Bojonggede and Cibinong to elite settlement in Cibenon. Schools, offices, factories, commercial and recreational areas were mostly found in downtown. Shrubs in both segments consisted of grassland, bushes and border highways. The widest area of shrubs was located in Sukaraja. Shrubs were dominated by reed, bulrush, and Bermuda grass.

Barren land in both segments was found near new settlement and construction areas of factories and stadiums. The largest barren land was located in Cibinong which was caused by land clearing to build Bogor Stadium. Water bodies consist of streams, lake, dam, and reservoir. Most of the green space area around lakes and reservoirs are turned into tourist sites, such as in Situ Cilodong. Cumulatively, land use change in both segments from 1989-2012 indicated a reduction of the green space area by 2,575.57 ha, whereas non-green space increased by 2,575.57 ha. Each land use area was obtained from the processing of Landsat images from 1989, 2001 and 2012 with overall classification accuracy of 80%, 80% and 95.04%, respectively. Table 2 shows land use changes in 2nd and 3rd segments of Ciliwung middle-stream watershed from 1989-2012.

From 1989-2001, the land use area has increased for shrubs, built up areas, paddy fields and plantation forests, whereas it has decreased for mixed plantations, dryland agriculture, natural forests, water bodies and barren lands. Increased area of shrubs was caused by construction of golf course and the fallow period of paddy and crops. Reduction of mixed plantation areas mostly occurred in Bojonggede district and Cibinong district, Bogor regency, caused by the changes in land use from plantation into crops and expansion of residential areas.

From 2001-2012, the increase in area has occurred for built up areas, natural forests, barren lands, and paddy fields, whereas it has decreased for dryland agriculture, shrubs, mixed plantations, natural forests and water bodies. Increase of built up areas drastically occurred in Bojonggede District and Cibinong District, Bogor Regency. Decreased dry land agriculture was caused by land conversion into built up areas and plantation forests. Bogor City and Bogor Regency was the main centre of tapioca starch production in Bogor District, which resulted in dry land farms in both segments which was dominated by cassava crops. The decrease in the dry land agriculture area was the main reason for the decline in production due to shortages of tapioca raw materials.

Residential, commercial, and supporting infrastructures were the causes of rural-urban linkages (Rustiadi, Saefulhakim & Panuju, 2009). Rural-urban linkages in both segments were highly affected by the mobility of the people working in the Jakarta-Bogor-Depok-Tangerang-Bekasi (Jabodetabek) area and living in Bogor City and Bogor Regency. Development of satellite towns which become a buffer area of Jakarta and Bogor has resulted in rapid increase of residential, commercial, industrial areas, and infrastructure. Improved road access and public transportation led to the development of suburban areas into urban areas, especially in Bojonggede, Cibinong, Northern Bogor, and Sareal Land. Demand for land for the development of the region in both segments led to the conversion of green space area to non-green space area. Figure 2 shows land use in 2nd and 3rd segments of Ciliwung middle-stream watershed.

B. Driving Factors of Land Use and Land Cover Changes in 2nd and 3rd Segments of Ciliwung Middle-stream Watershed

Land use and land cover changes were caused by three main driving factors namely: population growth, demand for land, and land constraint. These driving factors were interrelated. Population growth implies increased demand for land to meet basic needs. But increased demand for land was not followed by land use area expansion due to land constrain. This has

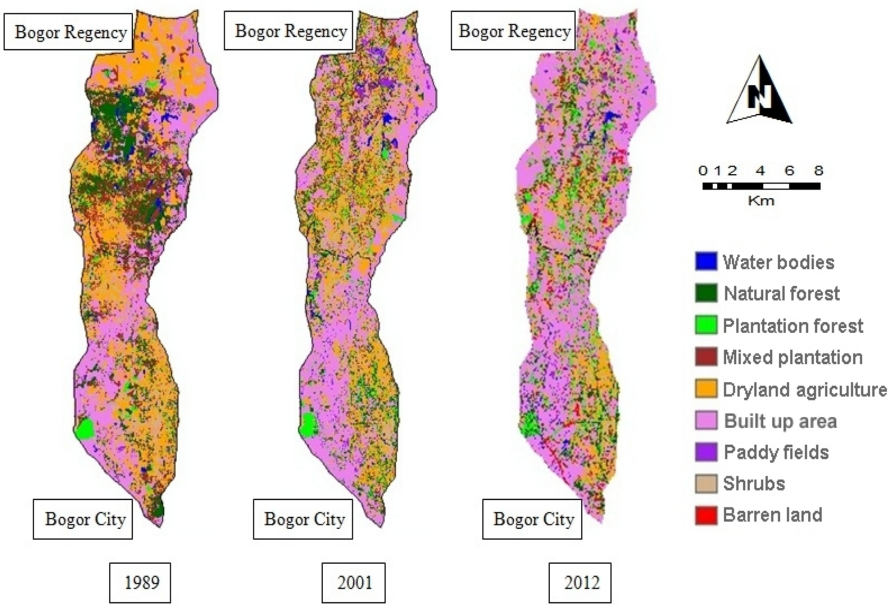

Figure 2. Land use in 2nd and 3rd segments of Ciliwung middlestream watershed

resulted in the conversion of green space area to accommodate the needs of non-green space areas, mainly to expand the built up area.

The first driving factor was population growth from 1990-2011. The population of 3rd segment increased from 246,200 people in 1990 to 371,934 people in 2012 whereas the population of 2nd segment from 205,505 people in 1990 to 466,870 in 2012. The total number of population in both segments has increased by 7.77% or 76,106 people from 1990-2001 but from 2001-2011 the population increased four times (31.75 % or 310,003 people). This matched with the West Java Province census data from 2010 (BPS West Java Province, 2010) that Bogor Regency had higher rate of population increase than Bogor City which was 3.15% compared to 2.40%. The rise of population growth led to increase of demand for land especially for residential-commercial-industrial areas and for infrastructures. Thuo (2013) stated that increased population in rural-urban fringe open new income opportunity in the service sector such as construction sector due to people's need for settlement especially for housing. .

Moniaga (2011) stated that one of the factors influencing population pressure on land was the people's livelihood structure. Employment changes of people occurred in both segments which were from jobs that required land such as agriculture and mining into jobs that required higher skills and education. It has indirectly affected people's activities in each land use. In 1990, agriculture and trade was still dominated in both segments that affected the expansion of the agricultural area of paddy fields and dry land agriculture because of the trade of food crops. People livelihood in 3rd segment mainly shifted from agriculture sector (37% of population) in 1990 to trade sector (30.43%) in 2012. People livelihood in 2nd segment mainly shifted from trade sector (64%) in 1990 to service sector (44%) in 2012. Livelihoods changes from 2001-2011 in agriculture and trade shifted to industry and services (banking and construction). The emergence of trade and service sectors caused land conversion from agriculture land use to build up area. Gyawali et al. (2013) stated that balancing rural-urban growth by establishing rural-urban business linkages was important so the urbanization effect like land conversion for urban sprawl can be reduced. Urban sprawl in both segments was caused by increased population and shifting livelihoods caused the expansion of built up areas for residential, commercial, and industrial purposes. The land conversion that occurred from 1989-2012, from green space area to built up areas amounted to 1,382.76 ha.

The second driving factor was increased demand for land along with the population growth in both segments. Based on the Regulation of the Minister of Environment No. 17/2009 on Guidelines for Determining Environmental Carrying Capacity in Regional Spatial Planning, land requirement calculation was based on the results of the calculation of land requirements for a decent life multiplied by the number of population. Area of land required for the necessities of life per person for decent living was divided by local rice productivities. Productivity of rice in Bogor Regency was 5,923 ton ha^{-1} $year^{-1}$, while in Bogor City it was 5,852 ton ha^{-1} $year^{-1}$. Decent living per people was assumed to be equivalent to 1 ton of rice/capita/year (stated assumption from MoE regulation No.17/2009). In 2011, demand for land in 3rd segment was 78,823.23 ha which was higher than in the 2nd segment where it was 63,556.73 ha. This was caused by the increased number of population who required land for basic needs, especially in the border areas between Depok City and Bogor City. Overshoot demand for land in both segments were 7 times from the actual area.

The third driving factor was land constraint. Increased demand for land from 1990-2011 exceeded the actual area in both segments. While land area in both segments from 1989-2012 was still the same which was 9.583,11 ha, but the demand in 2011 has reached 78.823,23 ha. So there was a deficit area of 69.240,12 ha. It can be concluded that both segments were

Table 3. Carbon stock and total CO_2eq emissions in each land use type at 2nd and 3rd segments of Ciliwung middle-stream watershed in 1989, 2001 and 2012

No.	Type of land use	1989	2001	2012
1.	Natural forests	115,102.01	54,233.35	45,005.98
2.	Plantations forests	35,336.96	51,674.44	109,416.70
3.	Mixed plantations	44,475.49	18,530.04	13,466.16
4.	Dry land agriculture	14,425.87	11,867.37	5,761.43
5.	Paddy fields	380.46	956.76	1.195.74
6.	Built up areas	6,966.13	9,105.55	13,162.05
7.	Shrubs	2,605.36	7,205.98	4,384.20
	Total ton C	219,292.27	153,573.48	192,392.27
	Total ton CO_2eq	804,802.64	563,614.67	706,079.62

dependent on the surrounding areas to meet the needs of the population living, mainly for food. Food supply in both segments was supported by the region of Ciliwung upstream or cross-regency such as Cianjur, Indramayu, Karawang and Subang. Those regencies were the biggest contributors of rice production in West Java.

C. Carbon Stock and CO_2eq Emissions in 2nd and 3rd Segments of Ciliwung Middle-stream Watershed

Carbon stock and CO_2eq emissions in 2nd and 3rd segments of Ciliwung middlestream watershed changed during 1989-2012. Both segments stored carbon up to 219,292.27 ton C in 1989, 153,573.48 ton C in 2001, and 192,392,27 in 2012. Despite enhancement of carbon stock from 2001-2012, the decline from 1989-2001 was still higher, cumulatively from 1989-2012 the carbon stock was reduced by 15,106 ton C. Table 3 shows carbon stock and total CO_2eq emissions in each type of land use at both segments of Ciliwung middle stream watershed in 1989, 2001 and 2012.

From 1989-2001, carbon stock reduction occurred in natural forests, mixed plantations, and dryland agriculture, whereas carbon stock increment occurred in plantation forests, paddy fields, built up areas, and shrubs. Reduction of natural forest's carbon stock in this period mostly happened in Bogor Regency. The increase in plantation forest's carbon stock was caused by the development of community forests in both segments. Plantation forest in both segments was mainly planted with fast-growing species white albizia (*Falcataria mollucana*) that influenced the increase of carbon stock in plantation forests.

Carbon stock increase in plantation forests was caused by the expansion of community forests. In this period, community forests in Bogor Regency and Bogor City expanded greatly due to its profitable market share. White albizia and teak became two dominant species in community forests in West Java including Bogor because of its ability to grow fast, easy access and wide open marketing (Rachman, Mile & Achmad, 2007). White albizia had a wide market share for raw materials for plywood, pulp and paper while teak had a market share for furniture and handicraft. In common community forest plantation was established by combining timber with crops or horticulture in the form of agroforestry (Hakim, Indartik & Suryandari, 2009). Timber species was planted without intersperse with crops or horticulture in community forests in both segments. In community forests in Cibinong, Bogor Regency, and Sareal Land, Bogor City, white albizia and teak was planted at a spacing of 3 m x 3 m and 4 m x 4 m with an average diameter ranging from 15-20 cm. Therefore, community forest's carbon stock in plantation forest was the highest carbon storage compared with other land uses.

Loss of 1 ton of carbon (ton C) equivalent to the release of 3.67 ton CO_2eq (Von

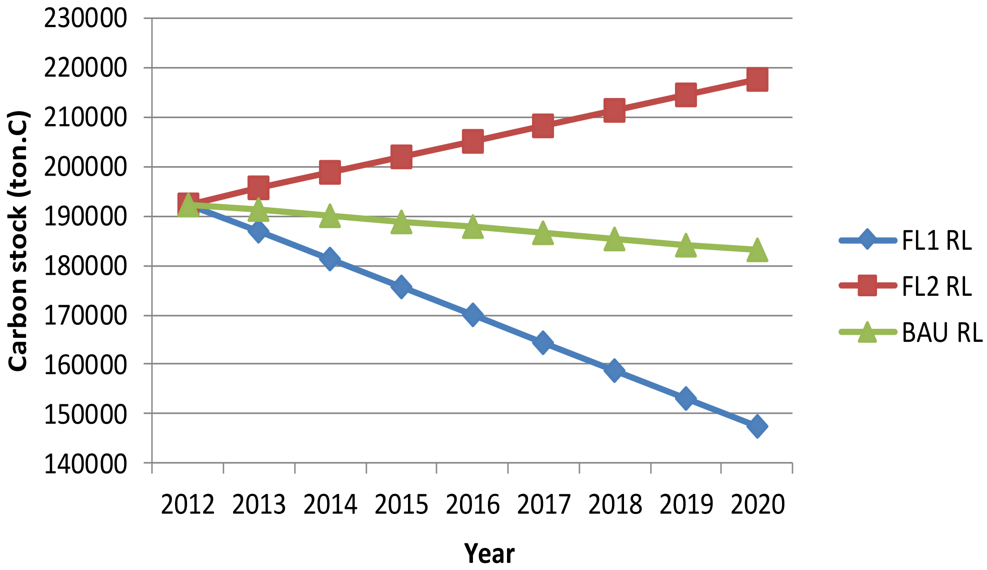

Figure 3. Reference Level projections in three Scenarios (BAU RL, FL1 RL, and FL2 RL) in 2nd and 3rd segments of Ciliwung middle-stream watershed

Mirbach, 2000). Accumulatively, from 1989-2001 the release of CO_2 emissions amounted to 241,188 ton CO_2eq which was caused by the loss of carbon stock in natural forests, mixed plantations, and dryland agriculture. Cumulatively from 1989-2012 the release of CO_2 emissions amounted to 98,723 ton CO_2eq. Whereas from 2001-2012 absorption of carbon amounted to 142,465 ton CO_2eq as a result of carbon stock enhancement in plantation forests, built up areas and paddy fields.

D. Reference Level Projections in 2nd and 3rd Segments of Ciliwung Middle-stream Watershed

Reference Level (RL) projections were determined by considering the changes in land use also carbon stock and CO_2eq emissions at both segments. Historical trends of land use were identified in the span of 8 years or until 2020. The projections focused on carbon stock changes caused by land use change activities from green space area into non-green space area and vice versa. Sub-national conditions were referenced from: 1) 20 year's spatial plan i.e. RTRW Bogor Regency 2005-2025 and RTRW Bogor City 2011-2031; 2) 20 year's regional plan i.e. RPJPD Bogor Regency 2005-2025 and RPJPD Bogor City 2005-2025. Based on these documents, Bogor Regency and Bogor City planned to meet the compulsory allocation of green space area of up to 30% of total area until 2025. Both regions have a green space area of about 10% of the total regional area. Therefore, for this analysis it was assumed that at sub-national (Bogor Regency and City) level planning the green space area should be increased by 20%.

In 2020, it will be evaluated how much of the achievement of GHG emission reduction on BAU conditions and how far the target of the 26% emission reduction of RAN GRK has been achieved. From the projections of land uses in 2020, the types of land use areas that reduced will be: natural forests (185.47 ha), mixed plantations (90.03 ha), dry land agriculture (618.85 ha), and water bodies (91.95 ha). Whereas the types of land uses that increase will be: plantation forests (932.36 ha), paddy fields (320.89 ha), built up areas (6,126.86 ha), shrubs (1,012.17 ha) and barren lands (204.37 ha).

Reference level projections were done by using three scenarios namely: BAU RL, FL1RL, and FL2 RL. Those scenarios were developed from projecting historical data of carbon stock and land use changes during 1989-2012, and has been projected 8 years forward or until 2020. The MAE error rate of historical data was 0.0267. It could be concluded that the forecast accuracy of the historical data was 97.33%. Figure 3 shows RL projections based on three scenarios, namely BAU RL, FL1 RL, and FL2 RL until 2020 in both segments.

In BAU RL scenario, carbon stock and CO2eq emissions until 2020 remained the same as the carbon stock history from 1989-2012 without considering spatial plan and regional plan in both segments. The BAU RL projection results showed a decrease in carbon stock by 1,169.57 ton C/year. So the BAU condition in both segments indicated that the total carbon stock stored was estimated at 183,035.7 ton C in 2020 or 9,356.57 ton C deficit from 2012. Carbon storage reduction in the BAU scenarios is also stated in Wohl, Dwire, Sutfin, Polvi and Bazan (2012) that historical changes in riverine complexity have likely reduced carbon storage in mountain's headwater rivers in Rocky Mountain National Park, USA.

In FL1 RL scenario, the assumption used in 2020 was an increase in the built up areas up 20% from 2012. Based on the documents of the spatial plan and regional plan, regional development strategies such as residential areas and infrastructure will be improved to develop new regional growth centers in remote areas. Pessimistic scenarios development was that the development in Bogor City and Bogor Regency will result in the decrease of green space in both regions. In FL1 RL projection, a decrease of green space area resulted in carbon stock reduction by 5,626.52 ton C year^{-1}. If this occurred, in 2020 both segments will store 147,380.10 ton C or 45,012.17 ton C deficit from 2012.

In FL2 RL scenario, the assumption used in 2020 was an increase in green space area up to 20%. Both regions considered to implement policy of allocating up to 30% of green space areas of the total regional area. Four basic strategies used for FL2 RL scenario, that is both regions were capable to optimize the utilization of vertical space, developing green space areas of up to 30%, limiting the development of the built up areas in urban centres by reducing the area by 5%, and maintain the function of the surrounding rural areas. In FL2 RL scenario it was estimated that there will be an increase in green space area that results in the increase of carbon stock by 3,152 ton C year^{-1}. If this occurs, in 2020 both segments were estimated to store 217,610 ton C carbon or a surplus by 25,218 ton C from 2012. From the three scenarios it can be concluded that FL2 RL is the best option for developing LCDS.

E. Low Carbon Development Strategies for Land Use Sector in 2nd Segment and 3rd Segment of Ciliwung Middle-stream Watershed

Low carbon development strategies (LCDS) for land use sector of Ciliwung middlestream watershed was developed based on analysis of policies and regulations related to existing conditions and the best RL scenario that can increase carbon stock. Forward looking optimistic scenario (FL2 RL), was the best projection that can significantly reduce carbon emission by increasing the green space area to 20%. In accordance with the authorities of the regency/city to support national program for reduction of GHG emissions, both governments of Bogor Regency and Bogor City are responsible for the implementation of GHG emission reduction, application of relevant policies, stakeholder consultations, and also have policies in place to support the plan to increase green space and control the utilization of Ciliwung watershed area. Policy analysis for the reduction of carbon emissions in 2nd and 3rd segments of Ciliwung middle-stream watershed is presented in Table 4.

The results of FL2 RL projection which support the reduction of CO_2 emissions and increase carbon stock were consistent with the result of the policy analysis. Implementation strategy was based on the development options

Table 4. Policy analysis for the reduction of carbon emissions in 2nd and 3rd segments of Ciliwung middle-stream watershed

RL scenario	Supportive existing policy options	Non-supportive existing policy options	Strategies/policies needed	Follow-up plan
Additional green space area up to 20%	1. Green space area allocation up to 30% at regency/city in UU No. 26/2007 about Spatial Planning. 2. Article 40 about land use control in catchment area in PP No. 37/2012 about Watershed Management. 3. Bogor as a water catchment area in Keppres No. 114/1999 about Regional Spatial Planning in Bogor-Puncak-Cianjur. 4. Government affairs division between government, provincial government, and local government about PP No. 38/2007. 5. Guidelines for provision and utilization of green space in urban areas about PermenPU No. 05/PRT/M/2008. 6. Green space area allocation and land use control in Perda Kabupaten Bogor No. 19/2008 about Bogor Regency Spatial Planning; Perda Kota Bogor No. 8/2011about Bogor City Spatial Planning; Perda Kabupaten Bogor No. 27/2008 about Bogor Regency RPJPD 2005-2025; Perda Kota Bogor No. 7/2009 about Bogor City RPJPD 2005-2025. 7. Guidelines for construction of private green space in residential areas and procurement of land acquisition and supporting components for public green space area in the document resume of West Java Regional Action Plan for GHG Reduction.	1. Inconsistency in the application of spatial planning in the field in Bogor Regency and Bogor City, especially for the control of built up areas development on river banks. 2. Violations of building permits about establishment of spatial planning policy in Bogor Regency and Bogor City. 3. Green space area addition had not been implemented in Bogor Regency and Bogor City.	1. Harmonization of the implementation of regency/city spatial plans on the ground. 2. Legal prosecution for violators of site plan and building permit in the regency and city, especially built up areas on river banks. 3. Relocation of settlements that are located at river banks. 4. The realization of additional green space area.	1. Control of land use to restore it according to its function (in green space area and non-green space area). 2. Accelerate the realization of additional green space areas as planned by local governments in both regions.

of the green space area and non-green space area. Low carbon development strategy aimed at adding green space area up to 20% through implementation of strategies based on type of green space area and non-green space area.

Implementation strategies of green space area consist of: protection, control, extension/awareness rising, and enforcement. Protection strategies will be implemented through conservation of the remaining natural forests in Ciliwung middlestream watershed, preserving existing public green space, and optimization of green space by planting tree species with higher carbon sequestration. Control strategies will be implemented by strengthening monitoring and evaluation of land use and land use changes. Extension/awareness rising strategies will be implemented by awareness rising and providing

Table 5. Low carbon development strategy for land use sector in 2nd and 3rd segments of Ciliwung middle-stream watershed

Type of land use	Scenario options	Problems	Implementation strategy
1. Green space area (consisting of natural forests, plantation forests, mixed plantations, dry land agriculture, and paddy fields)	1. Limiting the land conversion from green space area to non-green space area 2. Adding public and private green space area 3. Supporting the development of community forests and agroforestry 4. Planting species of tree with higher carbon sinks especially in public green space area (ex: *Samanea* sp. and *Cassia* sp.)	1. Population growth 2. Land constraint 3. Increased demand for land for built up areas The area of the existing green space is only 10% from the minimum target of 30%	1. Suggest to conserving the remaining natural forest area in Ciliwung middlestream watershed and maintain existing public green space. 2. Optimize existing public green space by planting species of trees with higher carbon sinks. 3. Strengthen monitoring and evaluation of land use control and land use change. 4. Improve socialization and incentives from local governments and the private sector to the public to support addiing of public/private green space. 5. Support community agroforestry and community forests through incentives. 6. Law enforcement
1. Non-green space (built up areas, barren lands, and water bodies)	1. Encouraging for residential green clusters 2. Limiting the land conversion of potential lands for green space area 3. Confirming that developers will build or have built for providing green space area 4. Legal action against violations of spatial rules, especially hoarding or narrowing the river to build residential-commercial-industrial areas	1. Land conversion to built up areas 2. The lack of monitoring and control of the spatial plan in the field 3. Frequent flooding and landslides in the river banks settlements	1. Engage social communities and community leaders in the socialization of Ciliwung watershed management. 2. Submit a proposal to build a public green space such as parks in dense and/or moderate settlements. 3. Provide relocation of residents from land acquisition, especially for people living on river banks. 4. Law enforcement for violators of spatial rules and building permits.

incentives for people to add public/private green space areas, and development of agroforestry and plantation forests. Enforcement strategies will be implemented by strict action against violations of the spatial law through letters of reprimand to the prosecution.

Implementation strategies on non-green space area consist of: extension/awareness raising, incentives, and enforcement. Extension/awareness raising strategies will be implemented by inclusion of social community and community leaders in socialization and management of both segments. Incentives strategies will be implemented by providing budget for adding green space area in new locations, relocation of residents whose lands have been redeemed for green space development and supporting infrastructures. Enforcement strategies will be implemented by strict action against violations of the spatial law through letters of reprimand to the prosecution. Low carbon development strategies on land use sector in both segments are summarized in Table 5.

IV. CONCLUSION

Land use change in 2nd and 3rd segments of Ciliwung middle-stream watershed from 1989-2012 indicated that reduction of green space area was caused by the increased population and land demand. The reduction of green space area from 1989-2012 accumulatively resulted in the reduction of carbon stock by 15,106 ton C. But the increase of green space area and carbon stock enhancement from 2001-2012 resulted in increased community forest and public green space areas in both segments which have the potential to support mitigation strategies for spatial arrangements especially in catchment areas.

By projecting the Reference Level of both segments with three options, namely: BAU, FL1 RL (forward looking, pesimistic scenario) and FL2 RL (forward looking, optimistic scenario), it was concluded that the best RL projection was the forward looking, optimistic scenario option by adding green space area up to 20% with an estimated carbon storing of 217,610 ton C or a surplus of 25,218 ton C from 2012. The best projection was used to develop LCDS in both segments. The LCDS aimed at adding green space up to 20% through the implementation of the strategies based on the type of green space area and non-green space area. Implementation strategies of green space area consist of protection, control, extension/awareness rising, and enforcement. Implementation strategies of non-green space area consist of extension/awareness raising, incentives, and enforcement.

ACKNOWLEDGEMENT

We thank you for Prof. Dr. Lilik Budi Prasetyo, for assistance and revision with spatial planning in Ciliwung watershed land use and Prof. Dr. Rizaldi Boer for review with statistical analysis. We also appreciate to Komunitas Peduli Cliwung and Komara Djaja, Ph.D for the support, assistance and input data of the manuscript

REFERENCES

Adinugroho, W.C. (2012). *Changes in soil carbon stock after deforestation and subsequent establishment of "Imperata" grassland in the Asian humid tropic* (Thesis). Bogor Agriculture University, Bogor.

Asdak, C. (2004). Hydrology and watershed management. Yogyakarta: Gadjah Mada University Press.

Badan Pusat Statistik (a). (1990). Potential village data collection: city of Bogor and Bogor Regency (in Bahasa Indonesia). Jakarta: Badan Pusat Statistik (a).

Badan Pusat Statistik (b). (2001). Potential village data collection: city of Bogor and Bogor Regency (in Bahasa Indonesia). Jakarta: Badan Pusat Statistik.

Badan Pusat Statistik (c). (2011). Potential village data collection: city of Bogor and Bogor Regency (in Bahasa Indonesia). Jakarta: Badan Pusat Statistik.

Badan Pusat Statistik Provinsi Jawa Barat. (2010). Forming socio-economic conditions of West Java in 2009-2010 (in Bahasa Indonesia). Bandung: BPS Provinsi Jawa Barat.

Dewi, S., Ekadinata, A., Galudra, G., & Johana, F. (2011). *LUWES: Land use planning for low emission development strategy*. Bogor: World Agroforestry Centre-ICRAF.

Gyawali, B. R., Hill, A., Banerjee, S., Chembezi, D., Christian, C.S., Bukenya, J., & Silitonga, M. (2013). Examining rural-urban population change in the Southeastern. *Journal of Rural Social Science*, *28*(2), 99–121.

Hakim, I., Indartik, & Suryandari, E.Y. (2009). Market analysis and wood trade systems of sengon in Wonosobo Regency and Temanggung Regency, Central Java (in Bahasa Indonesia). *Jurnal Penelitian Sosial dan Ekonomi Kehutanan*, *6*(2), 99–115.

Kusmana, C. (2003). Final report of the ciliwung integrated watershed management plan. Research Cooperation of Citarum-Ciliwung Watershed Management Research Institute with the Faculty of Forestry IPB (in Bahasa Indonesia). Bogor: BPDAS Citarum-Ciliwung dan Fakultas Kehutanan IPB.

Ministry of Environment (a). (2010). *Indonesia second national communication under the United Nations framework convention on climate change*. Jakarta: Ministry of Environment.

Ministry of Environment (b). (2011). Water quality monitoring of Ciliwung watershed. Center of Watershed Environmental Impact Control Facility, Deputy Minister for the Environment Technical Support and Capacity Building (in Bahasa Indonesia). Jakarta: Kementerian Lingkungan Hidup.

Mirbach, V. (2000). *Carbon budget accounting at the forest management unit level: An overview of issues and methods*. Ottawa: Canada's Model Forest Program, Natural Resources Canada.

Moniaga, V.R.B. (2011). Agricultural land support capability analysis (in Bahasa Indonesia). *Agri-Sosioekonomi*, *7*(2), 61–68.

Rachman, E., Mile, M.Y., & Achmad, B. (2007). Potential types of wood analysis for private forest in west java (in Bahasa Indonesia). In *prosiding pengembangan hutan rakyat mendukung kelestarian produksi kayu rakyat* (pp. 19–33). Bogor: Pusat Penelitian Sosial Ekonomi dan Kebijakan Kehutanan.

Rustiadi, E., Saefulhakim, S., & Panuju, D. (2009). *Regional planning and development (in Bahasa Indonesia)*. Jakarta: Yayasan Obor Indonesia.

Suryadi, I. (2012). Technical guide of emission reference levels calculation for land-based sector (in Bahasa Indonesia). Jakarta: UN-REDD Program Indonesia.

Thuo, A.D.M. (2013). Qualitive analysis of land use change pressures, conditions, and drivers in rural-urban fringes: A case of Nairobi rural-urban fringe, Kenya. *International Journal of Innovation and Applied Studies*, *3*, 820–828.

Wasis, B., Saharjo, B. H., Arifin, H. S., & Prasetyo, A. N. N. (2012). Land cover changes and their impact on carbon stock surfaces on the Ciliwung Watershed (in Bahasa Indonesia). *Silvikultur Tropika*, *3*(2), 108–113.

Wohl, E., Dwire, K., Sutfin, N., Polvi, L., & Bazan, R. (2012). Mechanism of carbon storage in mountainous headwater rivers. Nature *Communications*, *3*, 1263. doi:10.1028/ ncommc2274.

GUIDELINE FOR AUTHORS

AIM AND SCOPE
The journal publishes state of the art results of primary research findings and synthesized articles containing significant contribution to science and its theoretical application in areas related to the scope of Indonesian Forestry Research. Overseas works relevant to Indonesia conditions may be accepted for consideration.

LANGUAGE: All articles should be written in clear and concise English.

FORMAT MANUSCRIPT: To prepare your manuscript, please download a template from this link: http://ejournal.forda-mof.org/ejournal-litbang/files/IJFR_Template.docx. The entire manuscript should not exceed 20 pages. An electronic file of the manuscript should be submitted to the Indonesian Journal of Forestry Research Secretariat by following the publishing rules of IJFR through www.ejournal.forda-mof.org.

TITLE: A title should be brief and informative. Title must not exceed two lines and should reflect the content of the manuscript.

AUTHORS: Authors' names should appear immediately below the title, followed by Authors' affiliation and address. For more than one authors, affiliation detail and addresses should be mentioned in the right order. Email address of every author should be placed in the footnote.

ABSTRACT: Written in Bahasa Indonesia and English. Abstract should be no longer than 250 words, giving a brief summary of the content includes brief introduction, the reason for conducting the study, objectives, methods used, result and discussion and conclusion. Do not include tables, elaborate equations or references in the abstract.

KEYWORDS: Four to six keywords should be provided for indexing and abstracting. The word or term to be written under abstract; overviewing the issues, discussed, separately written from general to specific nature.

INTRODUCTION: State the objectives of the work and provide an adequate background of the research objectives, avoiding a detailed literature survey or a summary of the results.

THEORY/CALCULATION (if any): A theory or detailed calculation should be extended, not repeated, in the introduction. The theory or calculation mentioned should lay the foundation of the work.

MATERIAL AND METHOD: Provide sufficient detail of the research work to allow method to be reproduced. Describe the time and location of the study, materials and tools used, as well as research method. Methods already published should be indicated by a reference. Specific location should include the geographical information system. Only relevant modification to the method should be described clearly.

RESULT AND DISCUSSION: Results should be presented clearly and concisely. Discussion should explore the significance of the results work to the current condition or other research result, but not repeating the result. In case of large amount of result, result and discussion may be separated into sub chapter of result and sub chapter of discussion. Current reference (five years old reference) is an advantage to support the research finding than older references.

CONCLUSION: A conclusion section is required. It contains the main points of the article. It should not replicate the abstract, but might elaborate the significant results, possible applications and extensions of the work.

TABLE: Table should be numbered. Please use comma (,) and point (.) in all figures appropriately according to the English writing rule. Most charts graphs and tables are formated in one column wide (3 1/2 inches or 21 picas) or two-column wide (7 1/16 inches, 43 picas wide). Avoid sizing figures less than one column wide, as extreme enlargements may distort your images and result in poor reproduction. Therefore, it is better if the image is slightly larger, as a minor reduction in size should not have an adverse effect in the quality of the image.

DRAWING: Graphs and other drawing illustrations must be drawn in high contrast. Each drawing must be numbered as Figure with, titled given clear remarks. Graphic images should be formatted and saved using a suitable graphics processing program allowing creating the images as JPEG/ TIFF. Image quality is important to reproduce the graphics. Poor quality graphics could not be improved.

PHOTOGRAPH: Photograph with good contrast either in coloured or black and white and related to the text, must be titled and given clear remarks in numbered Figure. All photographs should be mentioned in the text and accompany to the manuscript in separate Microsoft word file. Photographs and grayscale figures should be prepared in 300 dpi resolution and saved with no compression, 8 bits per pixel (grayscale). Color graphics should be in the following formats: TIFF, Word, PowerPoint, Excel and PDF. The resolution of a RGB color TIFF file should be 400 dpi. Please supply a high quality hard copy or PDF proof of each image. If we cannot achieve a satisfactory color match using the electronic version of your files, we will have your hard copy scanned.

ACKNOWLEDGEMENT: Acknowledgement is recommended for persons or organizations who has already helped the authors in many ways. Sponsor and financial support acknowledgements may be placed in this section. Use the singular heading even if you have many acknowledgements.

REFERENCES: At least 10 references; referring to APA style 6th edition; organized alphabetically by author name; 80% from last 5 years issues; and 80% from primary reference sources, except for specific science textbooks (mathematics, taxonomy, climate). To properly credit the information sources, please use citation tools such as Mendeley or EndNote to create a bibliography, references and in-text citations. Mendeley is a free reference manager that can be downloaded at https://www.mendeley.com/download-mendeley-desktop

Reference List

American Society for Testing and Materials (ASTM). (1997). ASTM-D 297-93: Standard test methods for rubber products—Chemical analysis. West Conshohocken, USA: American Society for Testing of Materials.

Ayuk, E.T., Duguma, B., Franzel, S., Kengue, J., Mollet, M., Manga, T., & Zenkeng, P. (1999). Uses, management and economic potential of *Irvingia gabonensis* in the humid lowlands of Cameroon. *Forest Ecology and Management*, *113*, 1-19.

Badan Standardisasi Nasional. (2011). Gaharu SNI 7631:2011 (SNI.01-5009.1-1999). Indonesia: Badan Standardisasi Nasional.

Chen, H.Q., Wei, J.H., Yang, J.L., Ziang, Z., Yang, Y., Gao, J.-H., … Gong, B. (2012). Review : Chemical constituens of agarwood originating from the endemic genus Aquilaria plants. *Chemistry and Biodiversity*, 9, 236–250.

Kementerian Kehutanan. (2009). *Keputusan Menteri Kehutanan No.SK/328/Menhut-II/2009 tentang Penetapan DAS Prioritas dalam rangka RPJM tahun 2010-2014*. Jakarta: Sekretariat Jenderal.

Kenney, G.M., Cook, A., & Pelletier, J. (2009). *Prospects for reducing uninsured rates among children: How much can premium assistance programs help*. Retrieved from Urban Institute website: http://www.urban.org/url.cfm?ID=411823, at 1 October 2009.

Kurinobu, S. & Rimbawanto, A. (2002). Genetic improvement of plantation species in Indonesia. In A. Rimbawanto, & M. Susanto (Eds.), *Proceeding of International Conference on advances in genetic improvement of tropical tree species, 1-3 October 2002* (pp.1-6). Yogyakarta: Centre for Forest Biotechnology and Tree Improvement.

Lee, S.S. (2003). Pathology of tropical hardwood plantation in South-East Asia. *New Zealand Journal of Forestry Science*, *33*(3), 321-335.

Lim, S.C. (1998). Barringtonia J.R. Forster, & J.G. Forster. In M.S.M. Sosef, L.T. Hong, & S. Prawirohatmodjo (Eds.), P*lant Resources of South-East Asia 5(3): Timber trees: Lesser-known timbers*. (pp. 98-102). Leiden: Backhuys Publishers.

In Text Citation :

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.

IJFR TEMPLATE

TITLE SHOULD BE CONCISE, INFORMATIVE, AND CLEARLY REFLECT THE CONTENT OF THE MANUSCRIPT

First Author, Second Author, Third Author and Fourth Author
First, third, and fourth authors' current affiliations including current address
Second authors' current affiliations including current address

Received: .... Revised: .... Accepted: .... (Filled by IJFR)

TITLE SHOULD BE CONCISE, INFORMATIVE, AND CLEARLY REFLECT THE CONTENT OF THE MANUSCRIPT. The abstract should not exceed 300 words. The abstracts should be self-explanatory. It must include the reason for conducting the study, objectives, methods used, results and conclusion. Objective should briefly state the problem or issue addressed, in language accessible to a general scientific audience. Technology or Method must concisely summarize the technological innovation or method used to address the problem. Results should bring a brief summary of the results and findings. Conclusions should provide brief concluding remarks on your outcomes.

Keywords: Four to six keywords should be provided for indexing and abstracting. The word or term overviews the issues discussed, written in alphabetical order, separated by commas

JUDUL HARUS RINGKAS, INFORMATIF DAN SECARA JELAS MEREFLEKSIKAN ISI MANUSKRIP. Tuliskan terjemahan abstrak dalam bahasa Indonesia. Abstrak tidak lebih dari 300 kata. Abstrak menjelaskan keseluruhan isi artikel. Abstrak meliputi maksud, tujuan penelitian, metodologi yang digunakan, hasil dan kesimpulan. Maksud penelitian harus menjelaskan secara ringkas permasalahan yang diteliti menggunakan bahasa ilmiah umum yang mudah dimengerti oleh pembaca. Teknologi atau metodologi yang digunakan untuk pemecahan permasalahan penelitian harus dicantumkan secara lengkap dan ringkas dalam abstrak. Ringkasan hasil penelitian dan temuannya ditampilkan dalam ringkasan singkat. Kesimpulan harus menyatakan outcome yang dicapai dalam kegiatan penelitian.

Kata kunci: Empat sampai enam kata kunci untuk keperluan indeksasi dan abstraksi. Setiap kata mencakup isu yang dibahas dan diurutkan secara alphabet dipisahkan oleh tanda koma

---

Note:

- There should no nonstandard abbreviations, acknowledgements of support, references or footnotes in the abstract.
- In case of authors from one institution, footnote numbering is not necessary.

*Corresponding Author: e-mail: author@ forda-mof.org

I. INTRODUCTION

State the objectives of the work and provide an adequate background of the research objectives, avoiding a detailed literature survey or a summary of the results.

To prepare your manuscript, a template can be downloaded from this link: http://ejournal.forda-mof.org/ejournal-litbang/files/IJFR_Template.docx

Do not change the font sizes or line spacing to squeeze more text into a limited number of pages. Use italics for emphasis; do not underline. To insert images in Word, position the cursor at the insertion point and either use Insert | Picture | From File or copy the image to the Windows clipboard and then Edit | Paste Special | Picture (with "float over text" unchecked). IJFR will do the final formatting of your paper.

II. THEORY/CALCULATION (if any)

This chapter of theory/calculation is noncompulsory or optional. A theory or detailed calculation should be extended, not repeated, in the introduction. The theory of calculation (if any) mentioned should lay the foundation of the work.

III. MATERIAL AND METHOD

Provide sufficient detail of the research work to allow method to be reproduced. The material and method chapter can be divided into several sub-chapters.

A. Your Study Site/Location and/or materials

Describe the time and location of the study, materials and tools used as well as research method.

B. Your Methods

Methods already published should be indicated by a reference. Specific location should include the geographical information system. Only relevant modification to the method should be described clearly.

C. Your Analysis

Write the process of inspecting, cleaning, transforming and modeling data with the goal of discovering useful information, suggesting conclusions and supporting decision-making.

IV. RESULT AND DISCUSSION

Results should be presented clearly and concisely. Discussion should explore the significance of the results work to the current condition or other research result, but not repeating the result.

References must be used to support the research findings and expected to be written at least in the last five years.

V. CONCLUSION

A brief summary of the possible clinical implications of your work is required in the conclusion section. Conclusion contains the main points of the article. It should not replicate the abstract, but might elaborate the significant results, possible applications and extensions of the work.

ACKNOWLEDGEMENT

Acknowledgement is a must for persons or organizations who that have already helped the authors in many ways. Sponsor and financial support acknowledgements may also be placed in this section. Use the singular heading even if you have many acknowledgements.

REFERENCES

At least 10 references are listed according to American Psycological Association (APA) referencing style, 6th edition. References must be listed in alphabetical order by another name. Eighty percent of references should be cited from primary sources and published in the last five years. To properly credit the information sources, please use citation tools such as Mendeley or EndNote to create a bibliography, references and in-text citations. Mendeley is a free reference manager that can be downloaded at https://www.mendeley.com/download-mendeley-desktop/.

American Society for Testing and Materials (ASTM). (1997). ASTM-D 297-93: Standard test methods for rubber products—Chemical analysis. West Conshohocken, USA: American Society for Testing of Materials.

Ayuk, E.T., Duguma, B., Franzel, S., Kengue, J., Mollet, M., Manga, T., & Zenkeng, P. (1999). Uses, management and economic potential of Irvingia gabonensis in the humid lowlands of Cameroon. Forest Ecology and Management, 113, 1-19.

Badan Standardisasi Nasional. (2011). Gaharu SNI 7631:2011 (SNI.01-5009.1-1999). Indonesia: Badan Standardisasi Nasional.

Chen, H.Q., Wei, J.H., Yang, J.L., Ziang, Z., Yang, Y., Gao, J.-H., … Gong, B. (2012). Review : Chemical constituens of agarwood originating from the endemic genus Aquilaria plants. Chemistry and Biodiversity, 9, 236–250.

Kementerian Kehutanan. (2009). Keputusan Menteri Kehutanan No.SK/328/Menhut-II/2009 tentang Penetapan DAS Prioritas dalam rangka RPJM tahun 2010-2014. Jakarta: Sekretariat Jenderal.

Kenney, G.M., Cook, A., & Pelletier, J. (2009). Prospects for reducing uninsured rates among children: How much can premium assistance programs help. Retrieved from Urban Institute website: http://www.urban.org/url.cfm?ID=411823, at 1 October 2009.

Kurinobu, S. & Rimbawanto, A. (2002). Genetic improvement of plantation species in Indonesia. In A. Rimbawanto, & M. Susanto (Eds.), Proceeding of International Conference on advances in genetic improvement of tropical tree species, 1-3 October 2002 (pp.1-6). Yogyakarta: Centre for Forest Biotechnology and Tree Improvement.

Lee, S.S. (2003). Pathology of tropical hardwood plantation in South-East Asia. New Zealand Journal of Forestry Science, 33(3), 321-335.

Lim, S.C. (1998). Barringtonia J.R. Forster, & J.G. Forster. In M.S.M. Sosef, L.T. Hong, & S. Prawirohatmodjo (Eds.), Plant Resources of South-East Asia 5(3): Timber trees: Lesser-known timbers. (pp. 98-102). Leiden: Backhuys Publishers.

Matsuo, M., Yokoyama, M., Umemura, K., Sugiyama, J., Kawai, S., Gril, J., …Imamura, M. (2011). Aging of wood: analysis of color changes during natural aging and heat treatment. Holzforschung, 65, 361-368.

Pallardy, S.G. (2008). Physiology of woody plants (4th ed.). London: Elsevier Inc.

Raghavendra, A.S. (1991). Physiology of trees. USA: John Willey and Sons Inc.

Salampessy, F. (2009). Strategi dan teknik pemasaran gaharu di Indonesia. Paper presented at Workshop pengembangan teknologi produksi gaharu berbasis pada pemberdayaan masyarakat di sekitar hutan, Bogor 29 April 2009.

Thuo, A.D.M. (2013). Qualitive analysis of land use change pressures, conditions, and drivers in rural-urban fringes: A case of Nairobi rural-urban fringe, Kenya. International Journal of Innovation and Applied Studies, 3, 820–828.

Wezel, A., Rajot, J.L., & Herbrig, C. (2000). Influence of shrubs on soil characteristics and their function in Sahelian agro-ecosystems in semi-arid Niger. Journal of Arid Environment, 44, 383-398. doi:10.1006/jare.1999.0609.

Wohl, E., Dwire, K., Sutfin, N., Polvi, L., & Bazan, R. (2012). Mechanism of carbon storage in mountainous headwater rivers. Nature Communications, 3, 1263. doi:10.1028/ncommc2274.

Ministry of Environment and Forestry
Research, Development and Innovation Agency
Indonesia

9 772355 707002