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IMAGING TROPICAL PEATLAND AND AQUIFER POTENTIAL IN SOUTH SUMATRA USING ELECTRICAL RESISTIVITY TOMOGRAPHY

(*PENCITRAAN LAHAN GAMBUT TROPIS DAN POTENSI AQUIFER DI SUMATERA SELATAN MENGGUNAKAN TOMOGRAFI RESISTIVI TAS LISTRIK*)

Indonesia memilika area lahan gambut tropis terluas di dunia. Di Pulau Sumatera, gambut tersebar di 11 area dan yang terluas berada di Riau (60,1%) dan Sumatera Selatan (19,6%). Penelitian ini berlokasi di Kabupaten Ogan Komering Ilir, Provinsi Sumatera Selatan. Penelitian ini menggunakan metode *Electrical Resistivity Tomography* (ERT) untuk menggambarkan gambut dan kondisi bawah permukaannya. Penelitian ini menggunakan konfigurasi *dipole-dipole* dengan 72 elektroda. Penelitian ini bertujuan untuk mengidentifikasi sifat fisis (ketebalan dan tahanan jenis) lapisan gambut dan lapisan batuan dibawahnya dengan menggunakan metode ERT. Dari penampang ERT dan peta geologi, kami mengidentifikasi Alluvium (Qs), Formasi Kasai dan Batuan Granit. Dari hasil penelitian ini menunjukkan bahwa metode ERT ini dapat diterapkan untuk penggambaran ketebalan gambut dan fitur geologi lainya (struktur, stratigrafi, dan hidrogeologi). Hasil penelitian ini memperlihatkan resistivitas dari gambut berkisar antara 20–120 ohm-meter dengan ketebalan 2–5 meter. Di penampang ERT lainya, batuan granit dapat terlihat pada kedalaman 130–170 meter. Penentuan potensi akifer menggunakan interpretasi dari penampang ERT dan peta hidrogeologi. Potensi akifer terdapat di Formasi Kasai dengan ketebalan berkisar 2–20 meter. Properti fisik ini dapat mendukung konservasi lahan gambut dan analisis geoteknik.

Kata kunci: *Electrical Resistivity Tomography*, gambut, akifer, Sumatera Selatan

UDC/ODC 630*111.83:43 (594.47)

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CARBON LOSS AFFECTED BY FIRES ON VARIOUS FORESTS AND LAND TYPES IN SOUTH SUMATRA

(*KEHILANGAN CADANGAN KARBON AKIBAT KEBAKARAN PADA BERBAGAI TIPE HUTAN DAN LAHAN DI SUMATERA SELATAN*)

Kebakaran hutan dan lahan merupakan sumber emisi yang besar di Sumatera Selatan. Sejalan dengan kebijakan nasional, Provinsi Sumatera Selatan berkomitmen untuk mengurangi emisi, termasuk emisi dari kebakaran hutan dan lahan. Penelitian ini bertujuan untuk menilai kehilangan cadangan karbon akibat kebakaran hutan dan lahan pada berbagai srtatum/tipe hutan di Sumatera Selatan tahun 2015. Penelitian dilakukan dengan pengukuran ulang pada plot-plot pengukuran cadangan karbon yang terbakar tahun 2015 yang mencakup 3 kabupaten di Sumatera Selatan, yaitu Kabupaten Musi Banyuasin, Banyuasin, dan Musi Rawas. Kehilangan cadangan karbon dihitung dengan membandingkan cadangan karbon sebelum dan sesudah terbakar pada 4 stratum/tipe hutan yang terbakar yaitu hutan rawa gambut sekunder, hutan lahan kering sekunder, semak belukar rawa, dan hutan tanaman. Pengukuran stok karbon dilakukan pada plot berbentuk persegi berukuran 20 m x 50 m untuk berbagai tipe hutan alam dan berbentuk lingkaran dengan jari-jari 11,29 m dan 7,98 m masing-masing untuk hutan tanaman dengan umur < 4 tahun dan > 4 tahun. Selanjutnya, stok karbon pada masing-masing plot diukur untuk 3 pool karbon, yaitu di atas permukaan tanah, kayu mati dan seresah. Hasil penelitian menunjukkan bahwa kehilangan cadangan karbon bervariasi pada setiap stratum/ tipe hutan. Kehilangan karbon terbesar terjadi pada hutan rawa gambut sekunder sebesar 94,2 t/ha atau setara dengan emisi 345 t CO_2eq/ha. Kehilangan terbesar kedua terjadi pada hutan lahan kering sekunder sebesar 36,3 t/ha dan berikutnya pada hutan tanaman sebesar 18,5 t/ha dan semak belukar rawa sebesar 13,5 t/ha. Pada hutan rawa gambut sekunder dan hutan tanaman kehilangan karbon terbesar terjadi pada pool karbon biomass atas permukaan sedangkan pada hutan lahan kering sekunder dan semak belukar rawa, terjadi pada pool karbon kayu mati.

Kata kunci: Kehilangan karbon, kebakaran hutan, dan tipe hutan

UDC/ODC 630*811

Mahesh Wangkhem, Madhubala Sharma, and Chaman L. Sharma

COMPARATIVE WOOD ANATOMICAL PROPERTIES OF GENUS SYZYGIUM (FAMILY MYRTACEAE) FROM MANIPUR, INDIA

(*PERBANDINGAN KARAKTERISTIK ANATOMI KAYU GENUS SYZYGIUM (FAMILY MYRTACEAE) YANG BERASAL DARI MANIPUR, INDIA*)

Syzygium merupakan Family Myrtaceae yang sebagian besar terdiri dari pohon dan semak. Tujuan penelitian ini adalah untuk mempelajari karakteristik anatomi dan sifat fisik dari lima spesies Syzygium, yaitu Syzygium cumini, Syzygium fruticosum, Syzygium jambos, Syzygium nervosum, dan Syzygium praecox dan untuk melihat variasi intra dan antar spesies. Contoh uji diambil dari batang lurus setinggi dada dengan kondisi pohon yang bertajuk relatif seragam. Hasil penelitian menunjukkan bahwa karakteristik anatomi semua spesies yang dipelajari berciri relatif sama, yaitu bidang perforasi sederhana, noktah antar-pembuluh berumbai, sel parenkim jari-jari disjungtif, difus, difus-in-agregat, vasicentric, aliform dan konfluen aksial parenkima, difus porus dan frusicosum tidak jelas. Pembuluh sebagian besar berbentuk silinder dengan ekor kecil atau panjang di satu atau kedua ujungnya di semua spesies kecuali berbentuk tabung di S. jambos dan berbentuk silinder di S. fruticosum. Penebalan spiral dijumpai di bagian ekor S. nervosum dan S. fruticosum. Serat berdinding tipis dan tidak bersekat. Serabut bersekat sesekali dijumpai pada trakeid vasicentric jenis S. nervosum dan S. jambos. Sel kristal dalam jari-jari dijumpai pada jenis S. nervosum dan S. fruticosum dan badan silika di parenkima aksial jenis S. jambos. Persentase serat dan kepadatan kayu paling besar tercatat di S. jambos, sedangkan kadar air minimum tercatat di contoh uji S. jambos. Analisis komponen utama mengungkapkan hubungan yang erat di antara semua jenis. Oleh karena itu, karakteristik kualitatif bersama dengan karakteristik anatomi kuantitatif dapat digunakan sebagai dasar identifikasi jenis Syzygium.

Kata kunci: spesies Syzygium, karakteristik anatomi, kepadatan kayu, kadar air

UDC/ODC 630*841

Karnita Yuniarti, Barbara Ozarska, Graham Brodie, Gerry Harris, and Gary Waugh

THE DRYING PERFORMANCE AND POST-DRYING QUALITIES OF *Eucalyptus saligna* EXPOSED TO INTERMITTENT AND CONTINUOUS DRYING

(*PERFORMA DAN KUALITAS PENGERINGAN* Eucalyptus saligna *PADA PENGERINGAN INTERMITEN DAN KONTINYU*)

Eucalyptus saligna memiliki kecenderungan untuk mengalami cacat pengeringan, sehingga membatasi penggunaannya sebagai bahan konstruksi atau furnitur. Pengeringan intermiten, yang menerapkan fase pendinginan diantara fase pemanasan, berpotensi mengatasi masalah ini. Studi ini mengevaluasi pengaruh 3 skedul intermiten dan 1 skedul pengeringan kontinyu terhadap performa dan kualitas pengeringan jenis ini. Hasil studi menunjukkan papan-papan yang dikeringkan secara intermiten memiliki laju pengeringan lebih lambat (dari -9,4x10^{-3}%/jam ke -1,57 x10^{-2}%/jam) dari yang dikeringkan secara kontinyu (dari -5,12 x10^{-2}%/jam ke -1,03 x10^{-2}%/jam). Kedalaman kolaps yang terbentuk pada papan-papan yang dikeringkan secara intermiten juga lebih rendah (1,162-2,032 mm) dari yang dikeringkan secara kontinyu (5,12 mm). Walaupun demikian, penerapan suhu pengeringan yang lebih tinggi pada teknik intermiten dibandingkan dengan yang diterapkan pada teknik kontinyu berpotensi meningkatkan gradien kadar air, stress akhir pengeringan, panjang pecah ujung, persentase pecah dalam dan kedalaman pelengkungan kayu arah lebar sepanjang kayu.

Kata kunci: Eucalyptus saligna, performa pengeringan, cacat pengeringan, pengeringan intermiten, pengeringan kontinyu

UDC/ODC 630*812.7

Wahyu Dwianto, Ratih Damayanti, Teguh Darmawan, Prabu Satria Sejati, Fazhar Akbar, Danang Sudarwoko Adi, Adik Bahanawan, Yusup Amin, and Dimas Triwibowo

BENDING STRENGTH OF LIGNOCELLULOSIC MATERIALS IN SOFTENING CONDITION

(*KEKUATAN LENTUR DARI BAHAN BERLIGNOCELLULOSA PADA KONDISI PELUNAKAN*)

Rotan dan bambu lebih mudah dilengkungkan daripada kayu secara manual. Pertanyaan selanjutnya, apakah hal ini disebabkan oleh perilaku pelunakan komponen kimia atau struktur anatominya. Oleh karena itu, penelitian ini bertujuan untuk memahami perilaku pelunakan dan sifat viskoelastik kayu, rotan, dan bambu yang merupakan bahan berlignoselulosa. Material yang digunakan dalam percobaan adalah sampel kayu jati (Tectona grandis L.f.) cepat tumbuh berumur 9 tahun, rotan (Calamus sp.), dan bambu andong berumur 3 tahun (Gigantochloa pseudoarundinaceae (Steud.) Widjaja). Sampel diambil dari bagian bawah, tengah dan atas untuk kayu dan rotan, sedangkan untuk bambu dipotong dari ruas ke-1 sampai ke-20. Pengujian lentur statis dilakukan pada kondisi segar sebagai kontrol, kering udara, dan dilunakkan dengan pemanasan gelombang mikro (MW) selama satu menit untuk menentukan modulus patah (MOR) dan modulus elastisitas (MOE). Hasil penelitian menunjukkan bahwa nilai MOR dan MOE kayu, rotan, dan bambu meningkat dari kondisi segar ke kering udara, dan menurun dengan MW. Jika dibandingkan dengan kerapatan yang sama, terjadi peningkatan drastis dari nilai normalisasi MOR rotan pada kondisi kering udara, yaitu 2,5 kali lipat. Namun, penurunan nilai normalisasi MOR seluruhnya hampir sama, yaitu 0,5 kali lipat ketika dilunakkan dengan MW. Peningkatan luar biasa juga terjadi pada nilai normalisasi MOE rotan pada kondisi kering udara, yaitu 3,0 kali lipat dan menurun hampir nol dengan MW. Hasil ini menunjukkan bahwa rotan lebih mudah dilengkungkan, diikuti oleh bambu, kemudian kayu. Sifat hidrotermal komponen kimia secara signifikan mempengaruhi perubahan kekuatan (MOR) dan sifat elastis (MOE). Namun, perbedaan dari kekuatan lentur kayu, rotan, dan bambu tersebut lebih disebabkan oleh perbedaan struktur anatominya.

Kata kunci: Kekuatan lentur, bahan berlignoselulosa, kondisi pelunakan, struktur anatomi

UDC/ODC 630*922.2 (594.21)

Sylviani, Aneka Prawesti Suka, Surati and Dewi Ratna Kurniasari

SOCIAL CAPITAL IN MANAGING COMMUNITY PLANTATION FOREST: CASE IN KPH BOALEMO, GORONTALO PROVINCE

(*MODAL SOSIAL DALAM PENGELOLAAN HUTAN TANAMAN RAKYAT: STUDI KASUS DI KPH BOALEMO, PROVINSI GORONTALO*)

Hutan tanaman rakyat (HTR) merupakan salah satu alternatif yang diharapkan dapat memenuhi kebutuhan kayu. Keterbatasan modal, yang secara umum dipahami sebagai modal keuangan, dianggap sebagai permasalahan utama dalam pengembangan HTR. Namun demikian sebanarnya ada modal lain yang belum banyak diketahui dan dipahami oleh banyak pihak yaitu modal sosial. Penelitian ini bertujuan untuk mengetahui modal sosial yang dapat digunakan dalam mendorong keberhasilan pengelolaan HTR. Penelitian dilakukan di Desa Rumbia, Kabupaten Boalemo, Provinsi Gorontalo. Data yang dikumpulkan dianalisis menggunakan metode deskriptif kualitatifmelalui tiga langkah, yaitu reduksi data, penyajian data dan penarikan kesimpulan. Dalam penelitian ini, modal sosial dibahas dari dimensi kepercayaan, norma dan jaringan yang dapat menigkatkan efisiensi masyarakat dengan memfasilitasi tindakan yang terkoordinasi. Hasil penelitian menunjukan bahwa penguatan modal sosial yang berupa kepercayaan, norma, dan jaringan akan mendorong terciptanya kemandirian baik bagi petani maupun kelompok tani. Modal sosial yang tidak berfungsi dapat menimbulkan kesenjangan antar petani dan bahkan menjadi penghambat atau membatasi keterlibatan anggota kelompok tani dalam pengelolaan HTR. Petani juga memiliki kepercayaan yang tinggi kepada penyuluh kehutanan. Hal tersebut penting untuk terus dipelihara agar pendampingan melalui penyuluh kehutanan dapat mendorong pembangunan HTR secara optimal. Petani juga memiliki kepatuhan yang sangat tinggi terhadap norma sosial baik itu terhadap tradisi masyarakat, aturan agama ataupun aturan adat. Modal sosial yang telah dimiliki oleh anggota kelompok tani tersebut harus disikapi oleh pemerintah daerah dan pemerintah pusat dalam rangka mendorong keberhasilan pembangunan hutan tanaman rakyat.

Kata kunci : Modal sosial, hutan tanaman rakyat, kelompok tani hutan, Boalemo

IMAGING TROPICAL PEATLAND AND AQUIFER POTENTIAL IN SOUTH SUMATRA USING ELECTRICAL RESISTIVITY TOMOGRAPHY

Muhammad Rizki Ramdhani[1*], Acep Ruhimat[1], Wiyono[1], and Ahmad Barnes[2]

[1] Geological Agency, Ministry of Energy and Mineral Resources
Jl. Diponegoro No.57, Cihaur Geulis, Bandung, West Java, Indonesia
[2] Peatland Restoration Agency, Jl Teuku Umar 10, Jakarta Pusat, DKI Jakarta, Indonesia

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IMAGING TROPICAL PEATLAND AND AQUIFER POTENTIAL IN SOUTH SUMATRA USING ELECTRICAL RESISTIVITY TOMOGRAPHY. Indonesia has one of the largest tropical peatland areas in the world. In Sumatra Island, peatland spreads over 11 regions, and it is mainly found in Riau (60.1%) and South Sumatera (19.6%) Provinces. This study investigates the subsurface of tropical peatland in Ogan Komering Ilir Regency, South Sumatra Province. Data were recorded using Electrical Resistivity Tomography (ERT) method based on the sub-surface images of tropical peatland. This study was conducted based on the dipole-dipole configuration with 72 channels spread. This paper also studies the physical properties (thickness and electrical resistivity) of peatland and its substrate using ERT. In this study, the ERT section and the geological map identified Alluvium (Qs), Kasai Formation, and the Basement. The result shows the ERT is applicable for imaging the thickness of tropical peatland and other geological features (Aquifer, geological structures, and stratigraphy). The electrical resistivity of peat varies from 20-ohm meter to 120-ohm meter, and the thickness of peat varies from 2–5 meters. In some ERT sections, the basement was identified from 130 meters to 170 meters beneath the surface. The aquifer sweet spots were located from ERT Sections combined with the hydrogeological map. The aquifer was identified in Kasai Formation. The thickness of the aquifer layer is 2–20 meter. These physical properties may support peatland conservation (forest fire mitigation) and geotechnical analysis purposes.

Keywords: Electrical Resistivity Tomography, peatland, aquifer, South Sumatra

PENCITRAAN LAHAN GAMBUT TROPIS DAN POTENSI AQUIFER DI SUMATERA SELATAN MENGGUNAKAN TOMOGRAFI RESISTIVI TAS LISTRIK. Indonesia memiliki area lahan gambut tropis terluas di dunia. Di Pulau Sumatera, gambut tersebar di 11 area dan yang terluas berada di Riau (60,1%) dan Sumatera Selatan (19,6%). Penelitian ini berlokasi di Kabupaten Ogan Komering Ilir, Provinsi Sumatera Selatan. Penelitian ini menggunakan metode Electrical Resistivity Tomography (ERT) untuk menggambarkan gambut dan kondisi bawah permukaannya. Penelitian ini menggunakan konfigurasi dipole-dipole dengan 72 elektroda. Penelitian ini bertujuan untuk mengidentifikasi sifat fisis (ketebalan dan tahanan jenis) lapisan gambut dan lapisan batuan dibawahnya dengan menggunakan metode ERT. Dari penampang ERT dan peta geologi, kami mengidentifikasi Alluvium (Qs), Formasi Kasai dan Batuan Granit. Dari hasil penelitian ini menunjukkan bahwa metode ERT ini dapat diterapkan untuk penggambaran ketebalan gambut dan fitur geologi lainya (struktur, stratigrafi, dan hidrogeologi). Hasil penelitian ini memperlihatkan resistivitas dari gambut berkisar antara 20–120 ohm-meter dengan ketebalan 2–5 meter. Di penampang ERT lainnya, batuan granit dapat terlihat pada kedalaman 130–170 meter. Penentuan potensi akifer menggunakan interpretasi dari penampang ERT dan peta hidrogeologi. Potensi akifer terdapat di Formasi Kasai dengan ketebalan berkisar 2–20 meter. Properti fisik ini dapat mendukung konservasi lahan gambut dan analisis geoteknik.

Kata kunci: Electrical Resistivity Tomography, gambut, akifer, Sumatera Selatan

[*] Corresponding author: rizki.ramdhani@esdm.go.id

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I. INTRODUCTION

Generally, characteristics of tropical areas are high temperature throughout the year. In the tropics, peat occurs mostly in sub-coastal lowlands and is formed from rainforest trees and associated higher plants (Rieley & Page, 2016). The characteristics of tropical peatland are different from mineral soil such as irreversible drying, land subsidence, low in bearing capacity, availability of nutrient, and microorganism (Agus, Anda, Jamil, & Masganti, 2014). Tropical peatlands in their natural state are an important reservoir of biodiversity, carbon, and water (Andriesse, 1988). Indonesia contains 47% of the global area of tropical peatland (Page, Rieley, & Banks, 2011). In Indonesia, tropical peatlands are mostly found along the east coast of Sumatra and in the southern and western coastal regions of Kalimantan. Peatland area in Indonesia covers about 14.91 million ha spread out in Sumatra 6.44 million ha (43%), 4.78 million ha in Kalimantan (32%) and in Papua 3.69 million ha (25%)(Osaki, Nursyamsi, Noor, Wahyunto, & Segah, 2016).

Geologically, the investigation area took places in the South Sumatra Basin. Numerous geoscientists have described the tectonic setting and regional stratigraphy of South Sumatra

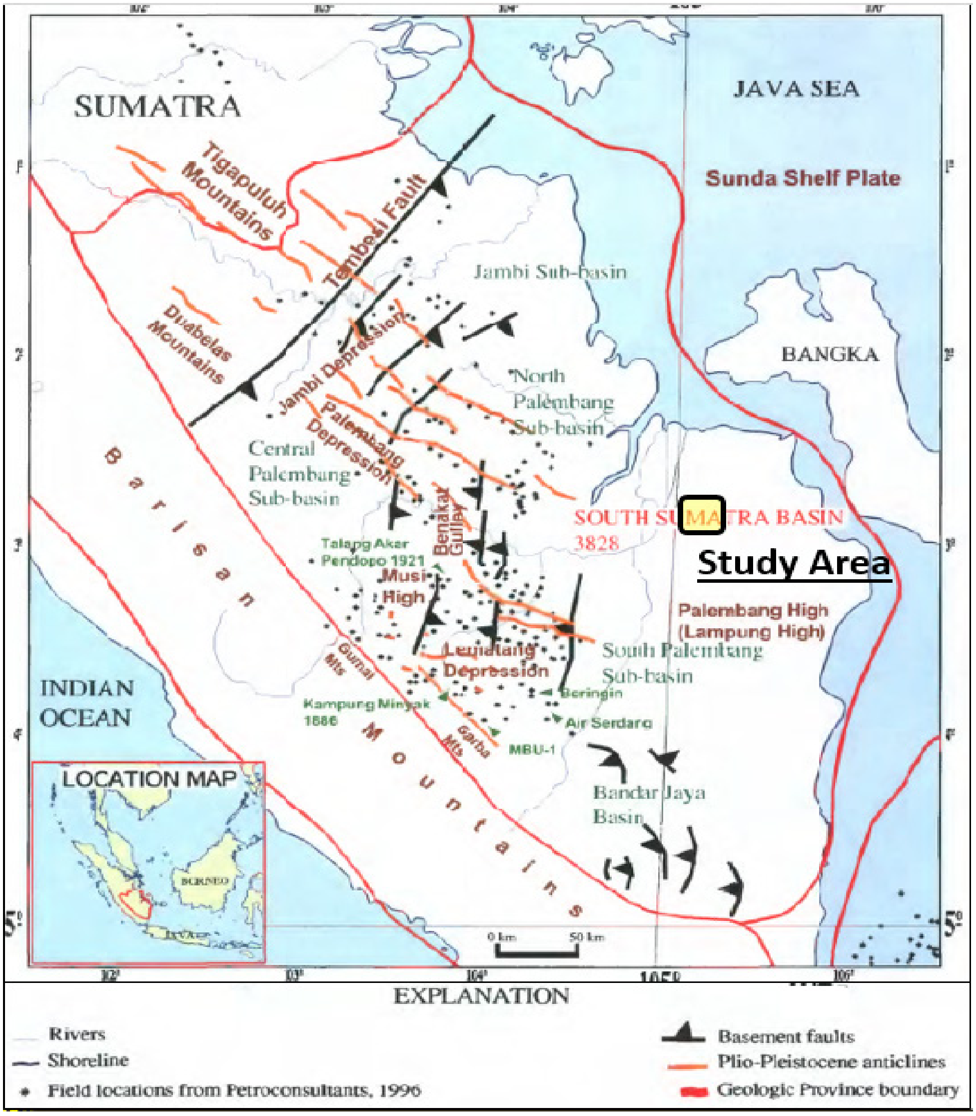


Figure 1. Location of study area in South Sumatra Basin

Basin. The South Sumatra Basin is located to the east of Barisan Mountains and extends into the offshore areas to the northeast and regarded as a back-arc basin bounded by the Barisan Mountains to the Southwest and the pre-tertiary of The Sunda Shelf to the Northeast (De Coster, 1974). The South Sumatra Basin systems were formed during the Eocene Period. The tectonic setting of Sumatra was influenced by the movement and collisions of the Indian Ocean and the Southeast Asia plates. The tectonic setting of South Sumatra Basin is dominated by northwest-southeast direction fault and fold, north-south direction fault, and northeast-southwest direction fault (Figure 1). The youngest geological deposits are the Palembang Formation which is sub-divided into three parts: (1) Lower Palembang (Air Benakat Formation), Middle Palembang (Muara Enim Formation), and Upper Palembang (Kasai Formation) (Figure 2).

The Air Benakat Formation was deposited during the regression that ended the deposition of Gumai Shale (Bishop, 2001). The thickness of the Lower Palembang part (Air Benakat Formation) ranges from 100 to 1000 m. The Muara Enim Formation was deposited as a shallow marine to continental sands, muds, and coals. The thickness of the Middle Palembang part (Muara Enim Formation) ranges 500 to 700 m in Muara Enim and Lahat area. The presence of the coal layer characterizes this part. The thickness of the Upper Palembang part (Kasai Formation) ranges 250–350 m at the lower part and 300–500 m at the upper part (Darman & Sidi, 2000). The quaternary deposits may overlie the Palembang Formation. These sediments are mainly deposited in the river and swamp forest. Tropical peatlands are composed of wood from swamp forest and can be characterized as hemic to sapric (depend on the degree of decomposition). The quality, landscape (shape) and extent of peat are controlled by several factors such as vegetation type, humidity, surface-groundwater regimes, physiographic and geological setting (Cameron,

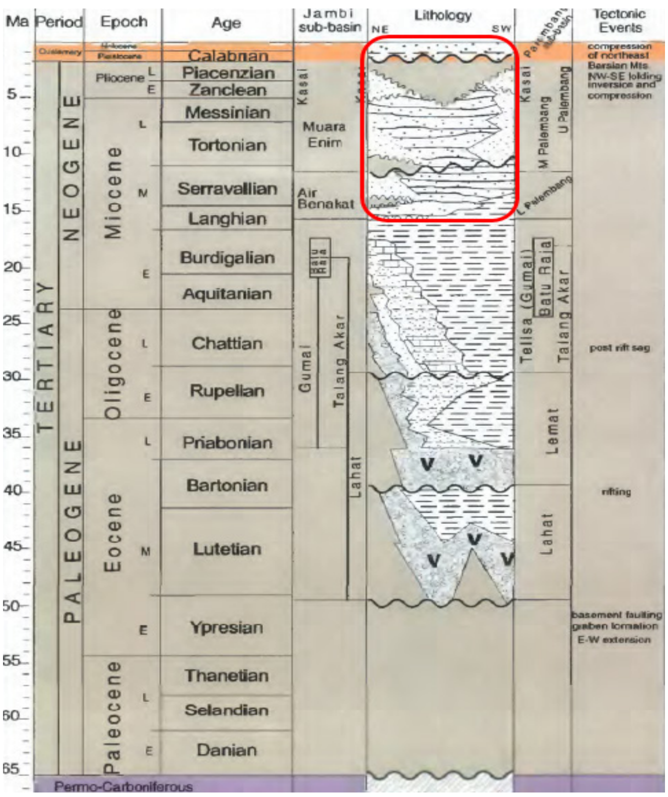


Figure 2. Stratigraphy of South Sumatra Basin and formation target of this study (Red Block)
Source: Bishop (2001)

Palmer, & Esterle, 1990). In Sumatra, peatland is spread over 11 areas, the largest peatlands area in Sumatra, mainly in Riau (60.1%) and South Sumatra (19.6%). In Sumatra island, peatland area was about 6.43 million ha that was divided up as shallow peat of about 1.77 million ha, medium peat of approximately 1.71 million ha, deep peat of about 1.24 million ha, and intense peat of about 1.72 million ha (Wahyunto, Nugroho, & Fahmuddin, 2014). In South Sumatra Province, Musi Banyuasin Regency, the thickness of peat varies from 0.3 m to 6.6 m (Subarnas & Ibrahim, 2018).

Peatland utilization for agriculture in Indonesia has a long history. However, greenhouse gases emissions and peatland fires issues have motivated the government to limit the usage of peatland in Indonesia. Since 2012 to 2016, more than 500 hotspots from peat swamp forests were regularly detected in South Sumatra (Putra, Sutriyono, Kadir, & Iskandar, 2019). During the dry season in 2019, at least 2000 hotspots were identified in South Sumatra (CNN, 2019). Indonesia has four principal regulations which directly affect the peatland utilization (Kittie, Schouten, & Hein, 2018). The four regulations require the adoption and integration of quite complicated technical practices to measure peatland distribution, depth, and hydrogeology of peatland. Aquifer existence is essential for peatland restoration effort and peat fires mitigation. Based on these requirements, geophysical method (ERT) can provide the technical data through field assessment.

Geophysical methods are usually applied for environmental investigation (Telford, Geldart, & Sheriff, 1990; Reynolds, 2011). Electrical Resistivity Tomography (ERT) method is potential to assist the understanding and imaging of peatland stratigraphy and hydrogeology. Some studies were investigated in northern peatland using ERT method. In Europe, Trappe and Kneisel (2019) used ERT for the assessment of lithology and subsurface water pathways. ERT and GPR were combined to identify structure, stratigraphy, hydrogeology and physical properties of peat in northern peatland (Xavier Comas, Slater, & Reeve, 2004, 2011; Kowalczyk, Zukowska, Mendecki, & Łukasiak, 2017; Sass, Friedmann, Haselwanter, & Wetzel, 2010; Slater & Reeve, 2002).

In Indonesia, ERT has been used for imaging tropical peatland in Tanjung Gunung and Pelang Village, West Kalimantan Province (Comas et al., 2015). The study sites were located in Perigi, Air Rumbai and Sungai Bungin Village, Ogan Komering Ilir Regency, South Sumatra Province. Our sites are 70 km from Palembang. According to the geological map of Tulung Selapan Area, our sites consist of alluvium and swamp deposit, Kasai Formation, Muara Enim Formation, Air Benakat Formation and Basement (Mangga, Sukardi, & Sidarto, 1993).

The sites were dominated by alluvium and swamp deposits which composed of gravels, sands, clays, and peat. Underlying of swamp deposits, Kasai Formation is composed of tuff, tuffaceous sand, sandstones, and iron oxide gravel. The basement (granite) was identified

Figure 3. Location of ERT acquisition (near the burnt area)

about 10 km from the investigation area (Figure 4). According to the hydrogeological map of Tulung Selapan Area, swamp deposits which are dominated by peat have low permeability (Pasaribu & Mudiana, 2013). Kasai Formation, which composed of tuff, tuffaceous sand, and sandstones have low to moderate permeability (Figure 5). This formation contains a potential aquifer layer. An aquifer is a saturated geological unit that can transmit water easily in significant amounts, and aquitard is a geological formation that can transfer water at slower rates than aquifer (SxEN, 2015). Perigi, Air Rumbai and Sungai Bungin villages were of the highest

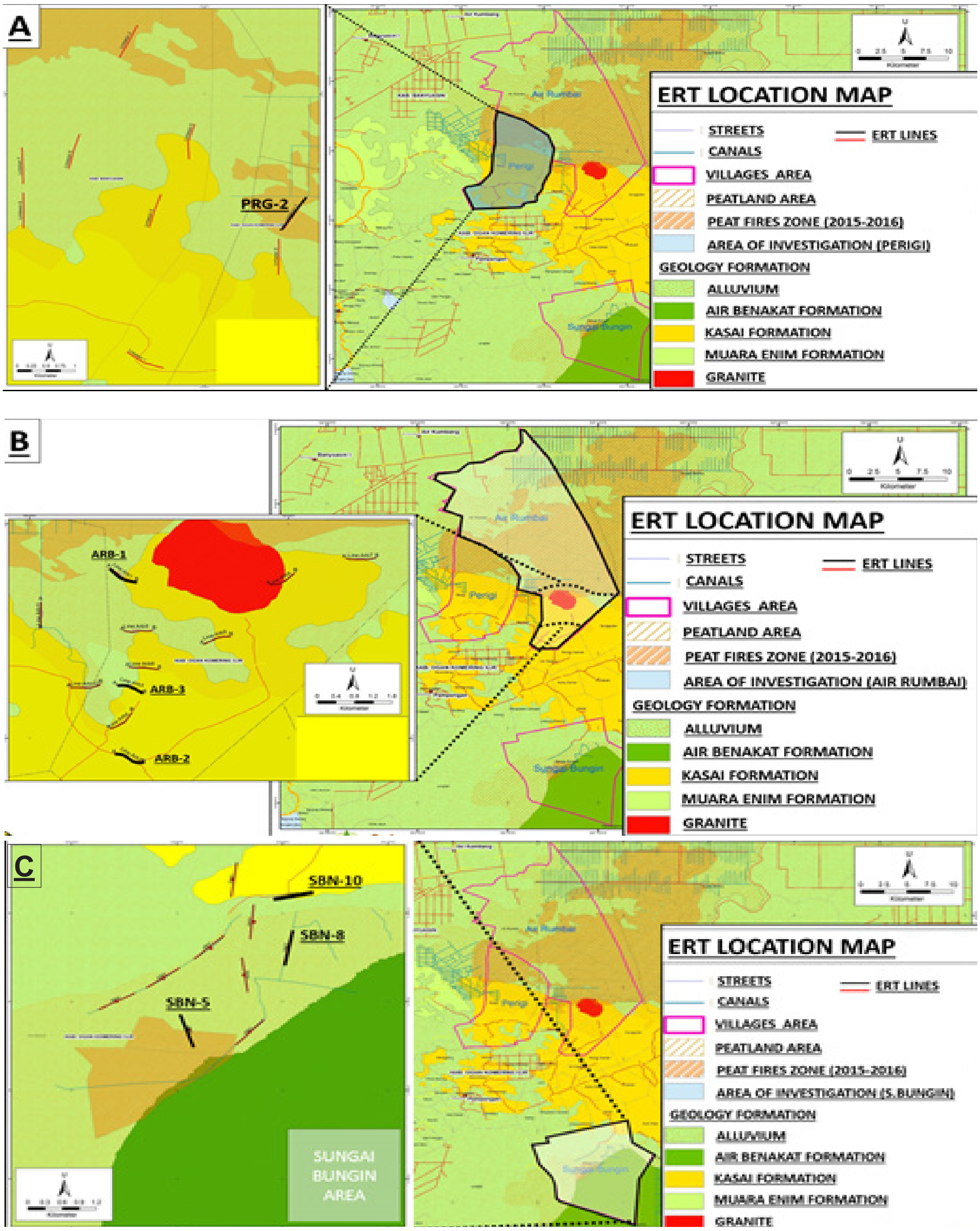
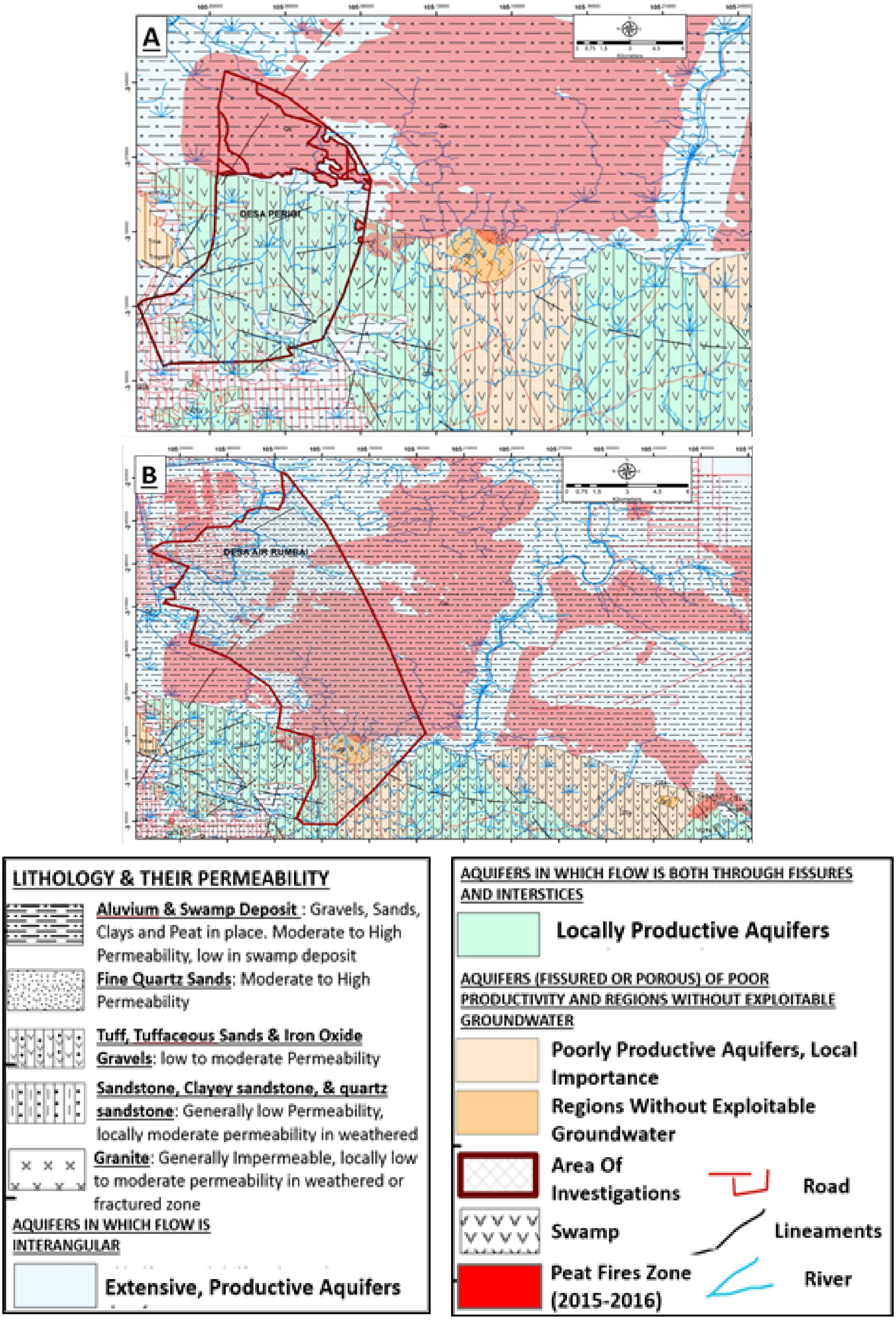


Figure 4. Geological map of Tulung Selapan Area and location of study, Perigi Village (A), Air Rumbai Village (B), and Sungai Bungin Village (C)

Source: Modified from Mangga, Sukardi & Sidarto (1993)


A
DESA PERIGI
B
DESA AIR RUMBAI
LITHOLOGY & THEIR PERMEABILITY
Aluvium & Swamp Deposit : Gravels, Sands, Clays and Peat in place. Moderate to High Permeability, low in swamp deposit
Fine Quartz Sands: Moderate to High Permeability
Tuff, Tuffaceous Sands & Iron Oxide Gravels: low to moderate Permeability
Sandstone, Clayey sandstone, & quartz sandstone: Generally low Permeability, locally moderate permeability in weathered
Granite: Generally Impermeable, locally low to moderate permeability in weathered or fractured zone
AQUIFERS IN WHICH FLOW IS INTERANGULAR
Extensive, Productive Aquifers
AQUIFERS IN WHICH FLOW IS BOTH THROUGH FISSURES AND INTERSTICES
Locally Productive Aquifers
AQUIFERS (FISSURED OR POROUS) OF POOR PRODUCTIVITY AND REGIONS WITHOUT EXPLOITABLE GROUNDWATER
Poorly Productive Aquifers, Local Importance
Regions Without Exploitable Groundwater
Area Of Investigations
Road
Swamp
Lineaments
Peat Fires Zone (2015-2016)
River

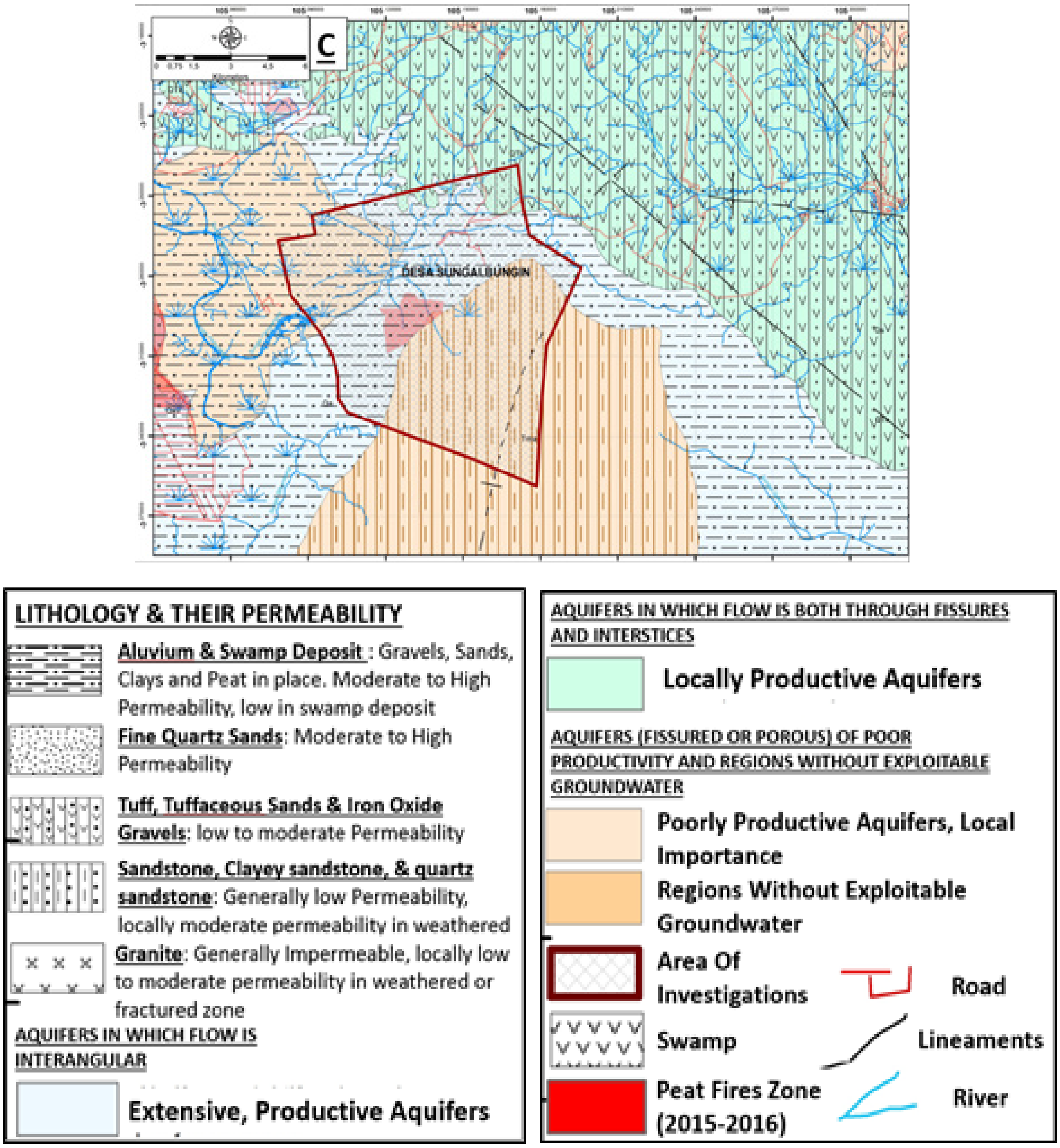


Figure 5. Hydrogeological map of Perigi (A), Air Rumbai (B) and Sungai Bungin (C)

Source: Modified from Pasaribu & Mudiana (2013)

priority of the investigation. Peat fires have burnt almost 30% of the peatland area in Perigi Village, 50% in Air Rumbai and Sungai Bungin Villages (Figure. 4). It is located in the southern side of of the burnt area, and about 20–40% peatland area was converted to rubber plantation. ERT measurements were conducted near the burnt area (Figure 3).

This study used electrical resistivity tomography to investigate subsurface of tropical peatland in Ogan Komering Ilir Regency, South Sumatra Province. This paper studies the Electrical Resistivity Tomography (ERT) for estimating and identifying physical properties of peat and its substrate (thickness and electrical resistivity). The method is also aiming for hydrogeological information of the peatland area. Advancing this knowledge could help to assist peatland management's decisions in Indonesia and improve assessment of peat.

II. MATERIAL AND METHOD

A. Electrical Resistivity Tomography

Electrical Resistivity Tomography (ERT) is a geophysical technique for imaging sub-surface structures from electrical resistivity measurements, which is made at the surface by multi electrodes. The true sub-surface resistivity could be estimated by making the measurements of potential differences at different positions of the current and potential electrodes, converting these values into apparent resistivity and then inverting the data set (Loke, 2011). The electrical resistivity of rocks depends on complex combinations of various electrical components consisting of solids (silicates, oxides, and metal), pores filled with air or liquid, and interfaces between solids and liquids (Yoshino, 2011). Peat is typically saturated and composed of 80–95% water (Hobbs, 1986). Electrical resistivity in peat depends on its physical properties such as organic and mineral content, mineral composition, moisture content, degree of peat decomposition, and water conductivity in peat matrix/pores. Tropical peat mostly consists of water with an organic carbon content (by weight) of 12 to 18%, or more, depending on the clay content of the peat, and the bulk density is in the range of 0.07–0.1 g/cm^3 (Taufik, Veldhuizen, Wösten, & van Lanen, 2019).

Electrical resistivity tomography was conducted using IRIS Syscal Pro 72 channel with automated data acquisition unit (Figure 6). Dipole-dipole configuration with 10 m electrode spacing was applied in these measurements. The sequence of measurements was made covering a total length of approximately 720 m, providing a maximum imaged depth of about 160–180 m. This parameter was chosen because of the requirement of deeper penetration for hydrogeological study. Field data obtained by ERT measurements were processed and interpreted using Res2DINV Software (Loke, 2000). The processing involves imputing topography data, editing the wrong datum, and running the inversion. The inversion routine used the least-square algorithm. The inversion result can be presented as a block model scheme or an interpolated contour map with a colour scale. The interpretation of the ERT section was performed based on the clustering of resistivity value from study literature (Loke, 2000) and combined with the geological and hydrogeological map.

This study has conducted twenty ERT lines. Because of the limitation in publication, this paper presented only three ERT sections (PRG-2, ARB-1 and SBN-8) from Perigi, Air Rumbai and Sungai Bungin Village. All of these lines were chosen because of the variation of the geological subsurface conditions (peat thickness, lithology and aquifer potential) and near the burnt area.

III. RESULT AND DISCUSSION

Electrical resistivity tomography has proven applicable for detecting changes in peat thickness, identifying and estimating the depth

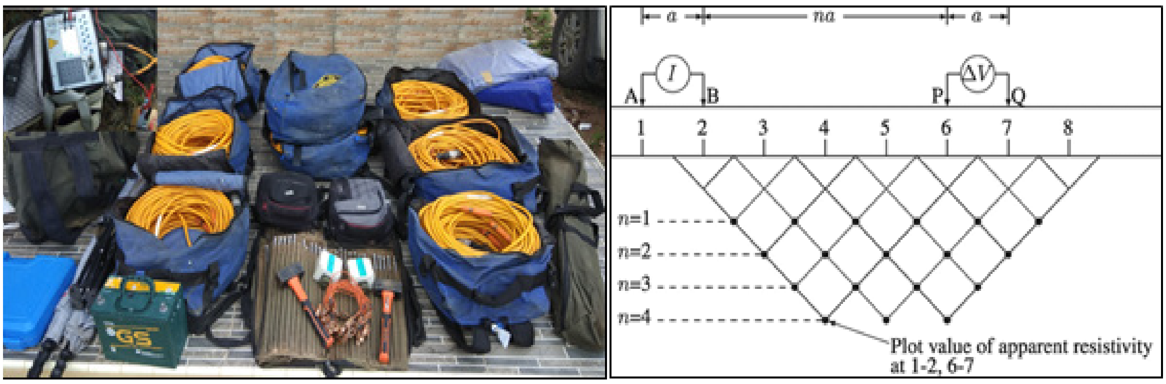


Figure 6. ERT IRIS Instruments (left) and the sequence of dipole-dipole measurement (right)

Table 1. Electrical resistivity cluster and interpretation

Resistivity (Ohm meter)	Lithology	Hydrogeology
< 1.7	sandy clay, tuff (contain saline water in place)	saline water
1.7 - 20	tuff, clay and silt stones	non-aquifer
20 - 120	sandy clay, sandstone, tuffaceous sand and peat	aquitard - Aquifer
120 - 626	oxide gravels and breccia	non-aquifer
>626	granite	aquifuge

of the aquifer (Figure 7, 8 & 9). The spacing between electrodes must be selected carefully so that the peat layer will not be hidden or generalized. The resistivity obtained from the ERT measurements varies from 0.2 to 7000-ohm m. The clustering of the resistivity value was made based on laboratory experiments (Loke, 2000)(Table 1).

A. ERT Section PRG-2

PRG-2 is located in peatland area. The area of measurement was surrounded by peat fires. The electrical resistivity obtained from the measurements varies from 0.34 to 445-ohm meter (Figure 7). From local information, there was a dry hole well with a total depth of 40 m located in the middle of the line acquisition. In this ERT section, the inversion result shows a relative conductive (less than 100-ohm meter) upper layer. This layer is correlated with the peat layer. Peat thickness varies from 2–5 meters. The wide variation on resistivity values depends on many physical properties of the peat. Groundwater level also affects the physical properties of the peat. (Walter, Lück, Heller, Bauriegel, & Zeitz, 2019) have shown that different levels of water saturation strongly influence bulk electrical conductivity (reciprocal of resistivity). In dry season groundwater level fall far below the surface, thereby decreasing moisture contents of the surface peat and creating vast amounts of dry fuel that are a fire hazard (Wösten, Clymans, Page, Rieley, & Limin, 2008).

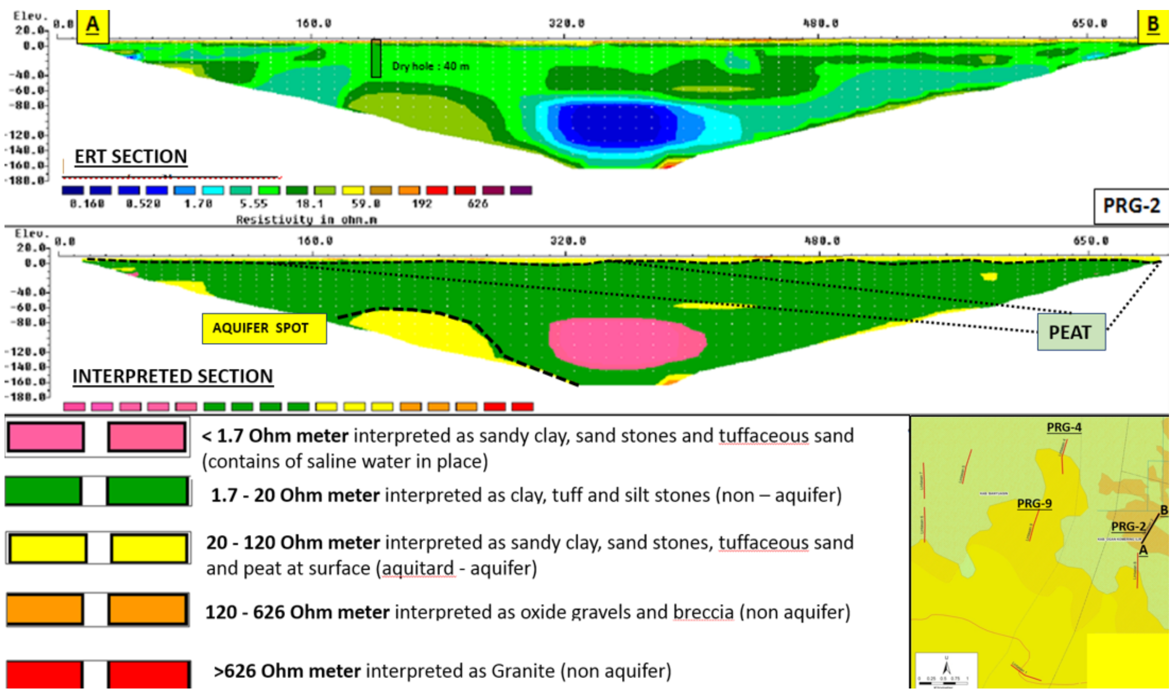


Figure 7. ERT PRG-4 section and its interpretation

Some part of the peatland area was burnt and resulted in many large pores and cracks on the peat surface and its substrate. This condition may cause higher ash content of the peat and could make the resistivity value bigger than usual. The degree of peat decomposition will affect the electrical resistivity of peat. (Asadi & Huat, 2009) with their resistivity laboratory tests have shown that the resistivity of peat decreased with the increasing degree of decomposition, water content, and temperature. Kurniain, Notohadikusumo, and Radjagukguk (2006) presented that development and cultivation in peatland caused changes in hydro-physical properties of peat soils. The hydro-physical properties of peat soil will affect electrical properties. The southern part of the line acquisition was converted to rubber plantation. The results of these laboratory experiments have not been explicitly confirmed by the ERT surveys presented in this paper.

Beneath the peat layer, the resistivity value varies from 1.7 to 20-ohm meter. This layer can be interpreted as a clay layer which is confirmed from a dry hole well data. From this ERT section, we have located aquifer sweet spot in Kasai Formation. It was located at 60 to 120 m beneath the surface, Kasai formation composed of sandy clay, sandstone, tuffaceous sand, oxide gravel, and breccia. The resistivity of this layer varies from 20 to 120-ohm meter. Resistivity value of less than 1-ohm meter was identified in this section. This value was correlated with saline water. Saline environments are mainly located in coastal zones, but they can also be found inland. Natural causes for salinization process are the presence of salt-rich rainwater or saline groundwater, high evaporation, and low precipitation. The main drivers for vertical salinity dynamics are precipitation and temperature (Walter, Lück, Bauriegel, Facklam, & Zeitz, 2018).

B. ERT Section ARB-1

This section is located near the plantation area. This section is dominated by moderate to high resistivity values (Figure 8). The electrical resistivity obtained from the measurements varies from 0.32 to over 1000-ohm meter. Aquifer potential was identified in the

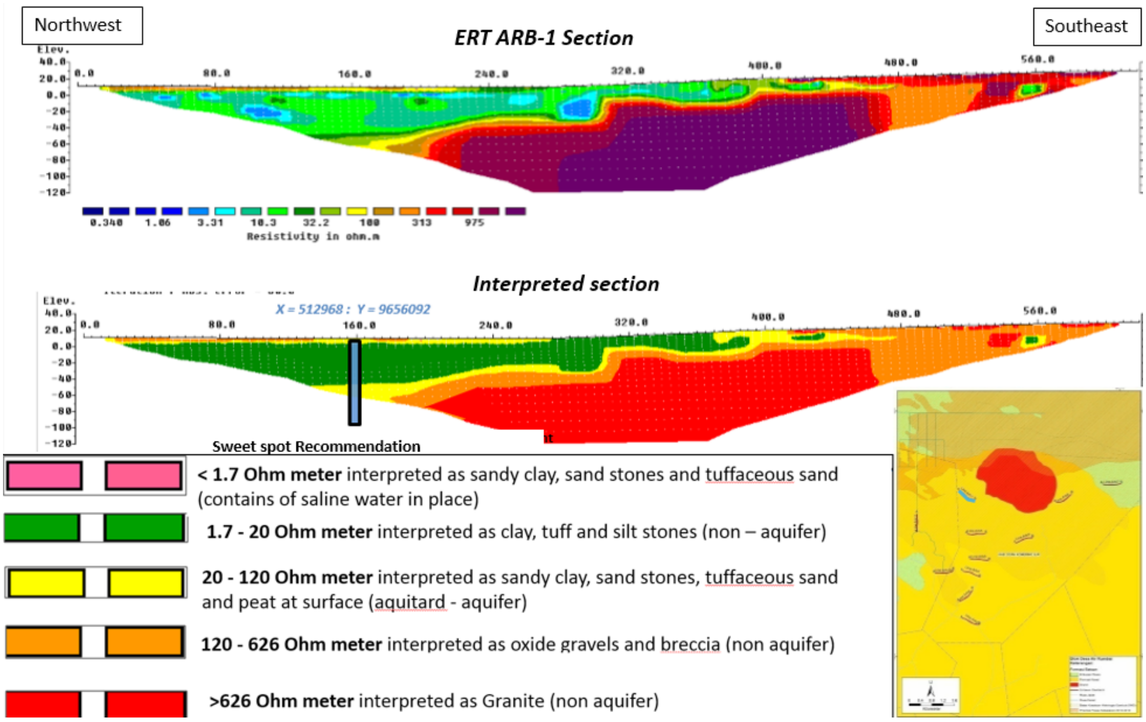


Figure 8. ERT ARB-2 section and its interpretation

northwest of the section. The aquifer was identified in Kasai Formation. This sweet spot was predicted at 50 to 80 m beneath the surface. Electrical resistivity of this layer varies from 20 to 120-ohm meter. The resistivity of this value can be interpreted as sandy clay, sandstones, and tuffaceous sand from Kasai Formation. The thickness of this layer varies from 5 to 20 meters. Overlaid the aquifer layer, the segment with low resistivity (1.7–20 ohm-meter) were identified form this section. This low resistivity value correlated with the clay layer. This low resistivity value is caused by surface conductivity of clay mineral. As clay minerals are flat, water can diffuse between the minerals and so increase the surface area. This condition supports the surface conductivity (Kirsch, 2009). High resistivity (>500 ohm-meter) values were obtained from this section. The resistivity of this value can be interpreted as a significant body of granite near the line of acquisition. Granite is an impermeable rock that wouldn't transfer any water (Fetter, 2001). Overlaid the granite, the aquifer thickened to the northwest side of the section. This interpretation is based on a literature study and the Geological Map of Tulung Selapan Area.

C. ERT Section SBN-8

This section is located in the peatland area. This section is dominated by low to moderate resistivity values (Figure 9). The electrical resistivity obtained from the measurements varies from 0.32 to 200-ohm meter. The ERT measurement of this section differs with the ERT in Perigi and Air Rumbai Village. In this measurement, we have tested the ERT measurement with different electrode spacing along the same line of acquisition. We have experimented with 10 m (Figure 9a) and 2.5 m (Figure 9b) electrode spacing. From this section, we identified the peat layer at the upper layer. The resistivity of the peat layer varies from 70 to >100 ohm-meter. The section with 2.5 m electrode spacing provided a better image of the peat layer. The high resistivity value of the peat layer correlated with many factors. The main factor is the physical properties of dried and burnt peat in the location of measurement. From this section, we can conclude that the ERT measurement with 2.5 m electrode spacing provided a better image than the ERT with 10 m spacing.

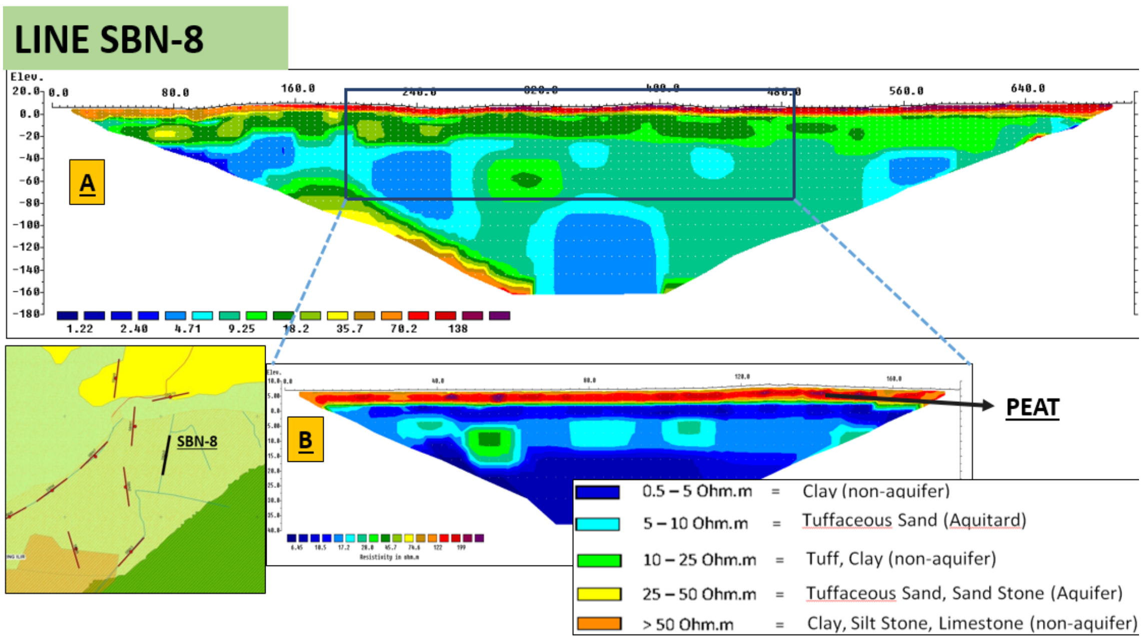


Figure 9. ERT SBN-8 section with 10 m (a) and 2.5 m (b) electrode spacing

IV. CONCLUSION

This study describes the application of electrical resistivity tomography for imaging subsurface of tropical peatland. The studies presented in this paper have cognitive and practical aspects. From ERT section, we identified physical properties of peat and its substrate. Electrical resistivity of peat varies from 20 to 120-ohm meter at the surface. The thickness of peat varies from 1 to 5 meter. The electrical resistivity of peat depends on its physical properties such as water content, degree of decomposition, moisture and organic material and temperature. Aquifer sweet spot was located in the middle of PRG-2 and northwest side of ARB-1 section and was predicted at a depth of 60 to 100 m beneath the surface. The aquifer was identified in Kasai formation, which has low to moderate permeability. From SBN-10 section, we can identify the peat thickness from ERT section with 2.5 m electrode spacing. This spacing was recommended for imaging peatland using ERT method.

This study may support activities for tropical peatland conservation in Indonesia. Tropical peatland in swamp forests is most vulnerable from fire hazard during the dry season. Peat thickness and aquifer must be identified for tropical peatland conservation, especially for fire hazard mitigation. Electrical resistivity tomography and other non-invasive geophysical methods could help mapping subsurface of tropical peatland in Indonesia. These technologies, combined with direct sampling measurements, are the best method for characterizing peat physical properties, distribution, and thickness estimation.

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CARBON LOSS AFFECTED BY FIRES ON VARIOUS FORESTS AND LAND TYPES IN SOUTH SUMATRA

Hengki Siahaan[1*], Adi Kunarso[1], Agus Sumadi[1], Purwanto[1], Teddy Rusolono[2], Tatang Tiryana[2], Hendy Sumantri[3], and Berthold Haasler[3]

[1]Environment and Forestry Research and Development Institute of Palembang
Jl. Kol H. Burlian Km 6.5 Puntikayu Palembang, Indonesia
[2]Faculty of Forestry, Bogor Agricultural University
Jl. Lingkar Akademik Kampus IPB, Dramaga, Bogor, West Java, Indonesia
[3]Biodiversity and Climate Change Project (Bioclime)
Jl. Jenderal Gatot Subroto, Manggala Wanabhakti Building, Block VII, 6th Floor, Jakarta 10270, Indonesia

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CARBON LOSS AFFECTED BY FIRES ON VARIOUS FORESTS AND LAND TYPES IN SOUTH SUMATRA. Forest and land fires are the primary sources of emissions in South Sumatra. In line with the national policy, South Sumatra Province commits to reduce emissions, including emissions from forest and land fires. This research was aimed to assess carbon loss affected by fire in 2015 that covered three districts in South Sumatra, i.e. Musi Banyuasin, Banyuasin, and Musi Rawas. The study was conducted by re-measurement of carbon stocks plots on four forests and land types, i.e. secondary peat swamp forest, secondary dryland forest, bushes swamp, and forest plantation. Carbon stocks measuring was conducted on sample plots in a rectangular shape of 20 m x 50 m of size for various types of natural forests and circle shape with a radius of 11.29 m (0.04 ha) and 7.98 m (0.02 ha) respectively for forest plantations of < 4 years and > 4 years old. Furthermore, carbon stocks in each plot were measured for three carbon pools of above-ground biomass, deadwood and litter. The result shows that carbon loss was varying with each forest and land type. The most significant number of carbon loss occurred on secondary peat swamp forest of 94.2 t/ha that is equivalent to the emission of 345.4 t CO_2eq. The second-largest carbon loss occurred on secondary dryland forest of 36.3 t/ha followed by forest plantation and bushes swamp of 18.5 t/ha and 13.5 t/ha, respectively. The enormous carbon loss on secondary peat swamp forest and forest plantation occurred on above-ground biomass pool but in secondary dry forest and bushes swamp occurred on the deadwood pool.

Keywords: Carbon loss, forest fires, and forest types

KEHILANGAN CADANGAN KARBON AKIBAT KEBAKARAN PADA BERBAGAI TIPE HUTAN DAN LAHAN DI SUMATERA SELATAN. Kebakaran hutan dan lahan merupakan sumber emisi yang besar di Sumatera Selatan. Sejalan dengan kebijakan nasional, Provinsi Sumatera Selatan berkomitmen untuk mengurangi emisi, termasuk emisi dari kebakaran hutan dan lahan. Penelitian ini bertujuan untuk menilai kehilangan cadangan karbon akibat kebakaran hutan dan lahan pada berbagai srtatum/tipe hutan di Sumatera Selatan tahun 2015. Penelitian dilakukan dengan pengukuran ulang pada plot-plot pengukuran cadangan karbon yang terbakar tahun 2015 yang mencakup 3 kabupaten di Sumatera Selatan, yaitu Kabupaten Musi Banyuasin, Banyuasin, dan Musi Rawas. Kehilangan cadangan karbon dihitung dengan membandingkan cadangan karbon sebelum dan sesudah terbakar pada 4 stratum/tipe hutan yang terbakar yaitu hutan rawa gambut sekunder, hutan lahan kering sekunder, semak belukar rawa, dan hutan tanaman. Pengukuran stok karbon dilakukan pada plot berbentuk persegi berukuran 20 m x 50 m untuk berbagai tipe hutan alam dan berbentuk lingkaran dengan jari-jari 11,29 m dan 7,98 m masing-masing untuk hutan tanaman dengan umur < 4 tahun dan > 4 tahun. Selanjutnya, stok karbon pada masing-masing plot diukur untuk 3 pool karbon, yaitu di atas permukaan tanah, kayu mati dan seresah. Hasil penelitian menunjukkan bahwa kehilangan cadangan karbon bervariasi pada setiap stratum/tipe hutan. Kehilangan karbon terbesar terjadi pada hutan rawa gambut sekunder sebesar 94,2 t/ha atau setara dengan emisi 345 t CO_2*eq/ha. Kehilangan terbesar kedua terjadi pada hutan lahan kering sekunder sebesar 36,3 t/ha dan berikutnya pada hutan tanaman sebesar 18,5 t/ha dan semak belukar rawa sebesar 13,5 t/ha. Pada hutan rawa gambut sekunder dan*

* Corresponding author: hengki_siahaan@yahoo.co.id

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hutan tanaman kehilangan karbon terbesar terjadi pada pool karbon biomass atas permukaan sedangkan pada hutan lahan kering sekunder dan semak belukar rawa, terjadi pada pool karbon kayu mati.

Kata kunci: Kehilangan karbon, kebakaran hutan, dan tipe hutan

I. INTRODUCTION

Forest and land fires affect the environment and human life seriously. In Sumatra Island, especially in South Sumatra, forest and land fires tend to occur repeatedly (Miettinen, Hooijer, & Wang, 2012) and almost every year. The last fire occurred in South Sumatra at the end of 2015 is thought to had the most significant impact on the environment and the economy after the 1997–1998 fires (Adriani, Moyer, Kendrick, Henry, & Wood, 2016). To solve the problem, the Indonesian government has made various efforts to prevent the occurrence of fire, either through their efforts through the program of Ministry of Environment and Forestry, or through international mechanism (Dharmawan, Arifanti, Lugina, Naito, & Eko, 2013; Wibowo, 2010).

Loss of carbon stock and biodiversity are some of the effects of forest and land fires on the environment. Repeated fires kill the majority of trees, reduce canopy cover by half, and favouring invasive grass (Balch et al., 2015). The fire is also a considerable contributor to emissions, mainly if it occurs on peatland. South Sumatra Province is one of the peatland areas in Indonesia and over the years has been a significant contributor to the emissions from forest and land fires (Agus, 2013; Gustina, 2014; Krisnawati, 2010).

In line with policies at the national level, the provincial government of South Sumatra has committed to reducing emissions, mainly from the forestry and peatland sectors, either through self-employment or through international cooperation mechanism. REDD+ (Reducing emissions from deforestation and forest degradation, the role of conservation, sustainable forest management, and enhancement of forest carbon stocks) is one of the international mechanism to reducing emissions from forestry and peatland sector that is implemented at the sub-national level. REDD+ implementation requires the Forest Reference Emission Level (FREL) as a basis of measuring the performance of reducing emissions; therefore, REDD+ implementation in a province requires a FREL arranged explicitly in a region with a high level of detail (tier 3) (Manuri, Lingenfelder, & Steimann, 2011).

As a basis for the specific FREL compiling with a high level of detail, Provincial Forestry Service of South Sumatra and Ministry of Environment and Forestry, in collaboration with GIZ Bioclime have prepared the high level of detail of emission factors on various types of forests in South Sumatra. The research was done by establishing 112 sample plots which are spread over seven forest types (primary dryland forest, secondary dryland forest, primary mangrove forest, secondary mangrove forest, primary peatland forest, secondary peatland forest, and forest plantation) and three types of non-forest areas, i.e. estate cropping, shrubland, bushes swamp (Tiryana et al., 2016). In addition, as the area of peat distribution that often suffers to fires, the arrangement of FREL in South Sumatra must take into account the emissions sourced from fires and peat decomposition.

Forest and land fires in South Sumatra in 2015 occurred with high intensity and extensive area coverage. The fires also occurred on sample plots that were used to prepare the emissions factor on various forest types in South Sumatra. Therefore, this research was aimed to assess the carbon loss affected by fires with the remeasurement of the burnt sample plots. The

Table 1. Locations and forest types of assessing the carbon losses in South Sumatra after fires in 2015

No.	Forest type	Location	Sample Plots
1.	Secondary peat swamp forest	Merang Kepahyang peatland forest	111, 113, 114, 115, 405, 406
2.	Bushes swamp	Merang Kepahyang peatland forest, KPHP Lakitan, SM. Bentayan Dangku	527, 528, 173, 378
3.	Secondary dryland forest	SM. Bentayan Dangku	316, 351
4.	Forest plantation	Eucalyptus plantation of PT. Musi Hutan Persada (MHP)	14, 68, 76

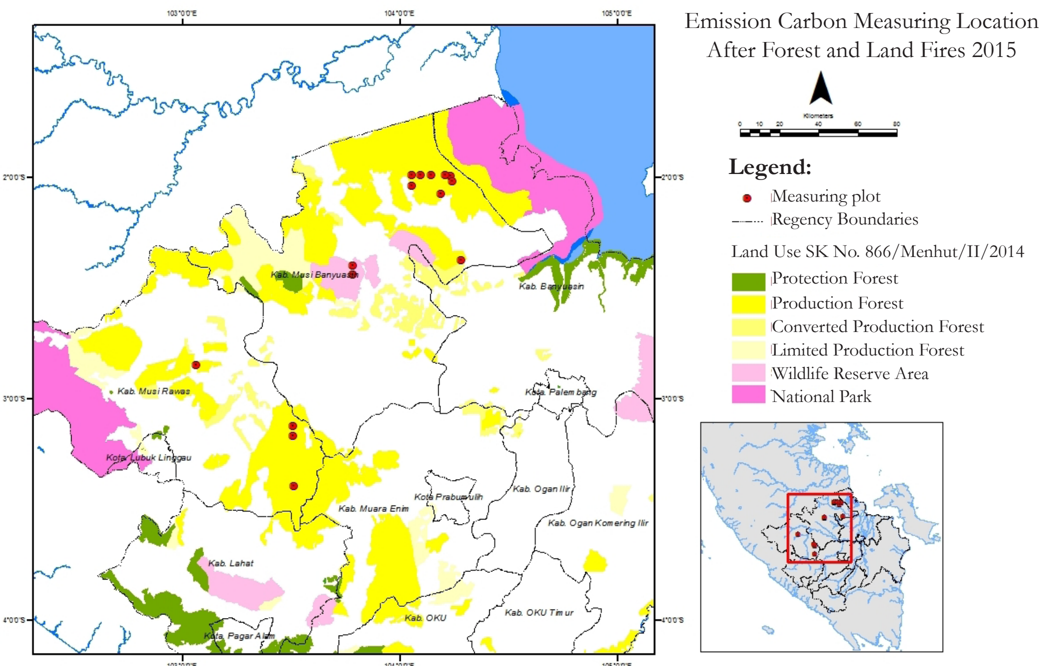

Figure 1. Site map of sample plots for assessing the carbon loss after fires on various forest and land types in South Sumatra

result of the study can be used as one of the information required for the preparation of the FREL document in South Sumatra.

II. MATERIAL AND METHOD

A. Location

Research location for assessing carbon loss affected by fires was done on the burnt areas at the end of 2015. The location includes three districts in South Sumatra, i.e. Musi Banyuasin, Banyuasin, and Musi Rawas districts and covers four forest and land types, i.e. secondary peat swamp forest, secondary dryland forest, bushes swamp, and forest plantation. Data collection was done by re-measurement of burnt sample plots established before the fires in 2015 (Tiryana et al., 2016). The plot placement was done by stratified systematic sampling design, but the number of sample plots on each forest type is determined by the size of the burnt area occurred in each plot. The sample plots in each location are presented in detail in Table 1, and the site map is shown in Figure 1.

B. Establishment of Sample Plots

The amount of carbon loss affected by forest and land fires can be calculated by comparing the carbon stock before and after the occurrence of the fires. The methods

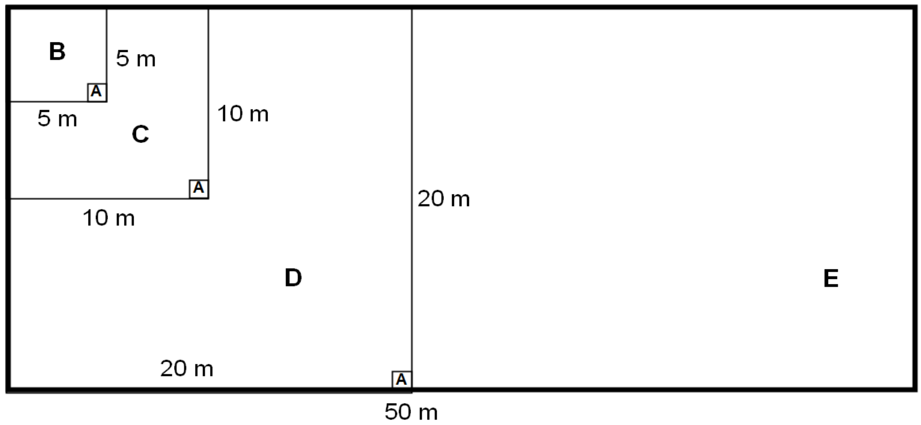

Figure 2. The size of the rectangular sample plots for carbon assessment in natural forest and mixed cultivated

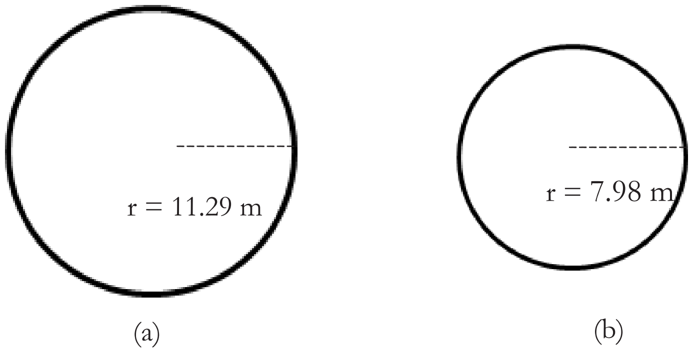

Figure 3. The size of the circle sample plots for carbon assessment in a forest and estate plantations: (a) age < 4 years and (b) age > 4 years

used refers to the Survey of Carbon Stock and Biodiversity in South Sumatra Guidance (Rusolono, Tiryana, & Purwanto, 2015).

The sample plot is a rectangular shape of 20 m x 50 m used for various types of natural forest, shrubland, and cultivated area (Figure 2). In the forest plantation and estate crop which composed of uniform vegetation, the measurement is relatively simple; therefore the sample plot is a circle shape (Figure 3). The radius of the circle sample plot is adjusted to the age of the plant. In forest plantation with the age of plant < 4 years, a circle plot with radius 7.98 m (area = 0.02 ha) is used and if the age of plant > 4 years, the radius of the circle plot is 11.29 m (area = 0.04 ha).

C. Data Analysis

The measurement and the analysis of carbon stock on the various forest types after fires in this study are restricted to 3 carbon pools, i.e. above-ground biomass (AGB), deadwood (DW), and litter (LTR). Carbon stock analysis on each pool was performed following the IPPC Guidelines 2006 and the Guidance of Carbon Stock and Biodiversity Survey in South Sumatra (Rusolono et al., 2015).

1. The measurement of above-ground biomass

Carbon pool on the above-ground biomass is the carbon stored in the live plants which consist of woody plants and understory vegetation. Woody plants were divided into four stages of growth based on the diameter of breast height (dbh), i.e. sapling (dbh 5–9 cm), pole (dbh 10–19 cm), medium tree (dbh 20-34 cm) and large tree (dbh ≥ 35 cm). Carbon stock measurement of woody plants performed on subplots B (5 m x 5 m), C (10

Table 2. Allometric models used for assessing the above-ground biomass

Tree species	Allometric model	Location	References
Forest plantation *Eucalyptus pellita*	$W_{ag} = 0.0678*D^{2.579}$	South Sumatra	Onrizal et al. (2009) In: Krisnawati, Imanuddin, & Adinugroho (2012)
Peatland forest mixed species	$W_{ag} = 0.15\ D^{2.095}*\rho^{0.664}*H^{0.552}$	Riau, South Sumatra	(Manuri et al., 2014)
Dryland forest mixed species	$Wag = 0.0673\ (\rho*D^2*H)^{0.976}$	Asia, Africa, America	(Chave et al., 2014)

m x 10 m), D (20 m x 20 m), and E (20 m x 50 m), (Figure 2) respectively, for a sapling, pole, medium and large tree. Understory vegetation covers all live plant above ground with a height below 1.5 meters. Carbon stock measurement of understory vegetation was performed on subplot A of 0.5 m x 0.5 m which was repeated three times on the corner of subplots B, C, and D.

Two methods measured carbon stock on above-ground biomass. Carbon stock on the understory vegetation was assessed by weighing the biomass directly to get the gross weight and then the sample was taken to get the dry weight in the laboratory. In this way, the dry weight or biomass of understorey vegetation per unit area in tons/ha was obtained. Meanwhile, the biomass of woody plants was assessed by measuring diameter and height of plants on each subplot and using allometric models appropriate for the forest types and the location where they were found (Table 2). Carbon stock on biomass was calculated by using the conversion factor of 0.47 (IPPC, 2006).

2. The measurement of litter

Litter is the remnants of dried and accumulated plant parts on the forest floor. The litter is restricted for the plant parts in the form of leaves, twigs, and the tree branches fallen on the forest floor with the diameter size of < 10 cm. The measurement of biomass on the litter was performed on the same subplot as for the understory vegetation, that is on subplot A, a rectangular plot of 0.5 m x 0.5 m was used. The understory vegetation and the litter were separated before each biomass was weighed to get their gross weight. Furthermore, from the samples of litter 300 gram was taken to get the dry weight in the laboratory.

3. The measurement of deadwood

Deadwood (necromass) is dead trees and their parts, which consisted of standing deadwood and fallen deadwood. Standing deadwood is classified into four classes of decay, i.e. class 1, 2, 3, and 4 in accordance to the guidance of carbon stock and biodiversity survey in South Sumatra (Rusolono et al., 2015). Based on the guidance, each of the decay class is explained as follows:

- Class 1: the dead tree with much branch and twig but does not have leaves
- Class 2: the fallen tree with the branch but does not have a twig and leaves
- Class 3: the dead tree with no branch but the stem still complete
- Class 4: the fallen tree with a broken stem like a stump.

Furthermore, the biomass of standing deadwood was calculated using the allometric model of live trees (Table 2) and then multiplied with the correction factor of 0.9, 0.8 and 0.7 respectively for standing deadwood class 1, 2, and 3. Whereas for standing deadwood class 4, the biomass was calculated by equation (1). The density of standing deadwood class 4 used in equation (1) is the result of the previously performed carbon stock survey (Table 3).

$$W_{dw4} = 0.25\ \pi\ (D/100)^2 *T * f * WD \quad ....(1)$$

Remarks: Wdw4 = dead wood biomass class 4, D = stem diameter (cm), T = height (m), f = form factor (0.6), and WD = wood density of deadwood.

Table 3. The average density of standing deadwood and fallen dead wood in various types of forest in South Sumatra

Deadwood types	Class	Average (g/cm^3)	Standard Deviation (g/cm^3)
Standing dead wood	1	0.559	0.092
	2	0.351	0.099
	3	0.389	0.107
	4	0.308	0.094
Fallen dead wood	1	0.560	0.175
	2	0.441	0.159
	3	0.354	0.153

Source: References: Tiryana et al. (2016)

Tabel 4. Carbon stock of above-ground biomass (*AGB*) before and after fires in various forest types in South Sumatra

Forest type	Carbon stock of AGB before the fires (t/ha)			Carbon stock of AGB after the fires (t/ha)		
	WP	UV	Total	WP	UV	Total
SPSF	105.3 ± 56.9	0.1 ± 0.1	105.4 ± 56.8	3.4 ± 5.3	1.7 ± 0.5	5.1 ± 5.0
BS	20.0 ± 16.3	1.7 ± 2.3	21.8 ± 15.7	17.9 ± 5.7	3.5 ± 1.9	21.4 ± 7.1
SDF	75.5 ± 22.2	0.0 ± 0.0	75.5 ± 22.2	68.7± 8.7	0.5 ± 0.3	69.2 ± 22.2
FP	15.9 ± 17.2	3.5 ± 1.9	19.5 ± 16.3	0.0 ± 0.1	2.1 ± 0.7	2.1 ± 16.3

Remarks: WP = woody plants, UV = understory vegetation, SPSF= secondary peat swamp forest, BS = bushes swamp, SDF = secondary dryland forest, FP = forest plantation

The measurement of the biomass of fallen dead wood was performed by the volumetric method. Based on this method, the biomass is obtained by multiplying the volume of fallen deadwood with its density. The density of fallen dead wood was adjusted to the result of carbon stock and biodiversity survey in South Sumatra (Tiryana et al., 2016) as shown in Table 3. The fallen wood volume was calculated with equation (2).

$$V_{ldw} = 0.25\ \pi\ ((D_p + D_u)/200)^2 .\ L \quad \text{..............(2)}$$

Remarks: Vldw = volume of fallen dead wood, Dp = large end diameter, Du = small end diameter, and L = length of fallen dead wood

III. RESULT AND DISCUSSION

A. Carbon Loss on Above Ground Biomass

Carbon loss affected by the fire on above-ground biomass (AGB), mainly occurs in woody plants. The highest carbon loss occurs in secondary peat swamp forest, i.e. in Merang Kepahyang forest area. The result shows that above-ground biomass of woody plants on peat swamp forest is high before the fire (Figure 4), an average of 105.3 t/ha and after the fire, only 3.4 t/ha is left, meaning there is a carbon loss of 101.9 t/ha or 96.77% of the initial amount (Table 4). The second-largest carbon loss of woody plants of above-ground biomass occurred in forest plantation, amounting to 15.9 t/ha. Still, from the percentage point of view, carbon loss in this forest type is the largest, reaching almost 100%. Carbon loss of woody plants of above-ground biomass on secondary dryland forest and bushes swamp is relatively small, at 6.8 t/ha (9%) and 2.1 t/ha (10.5%) respectively.

Differences in the numbers of carbon losses in different forest types are caused by differences in land characteristics in each forest type. This occurs because the natures and intensity of fires are influenced by the characteristics of the land where the fire occurred. Based on soil types, in

Figure 4. The condition of forest cover in Merang Kepahyang peat swamp forest before (left) and after fires (right)

the land and forest fires in South Sumatra in 2015 it was found that hotspots mostly occurred on peat soil, i.e. 180 hotspots with a hotspots density of 0.048 hotspots/km^2 (Tata, Narendra, & Mawazin, 2017). Fires in peat swamp forest containing thick, soft material cause fires not only to occur on the surface but also can reach up to the tree roots. Dry peat with shallow moisture after the last extreme drought will become a very combustible fuel (Ardiansyah, Boer, & Situmorang, 2017; Subiksa, Hartatik, & Agus, 2011). Fires like this will last a long time and will cause the whole tree to die. This is in contrast to fires in other forest types, which generally occur only on the surface so that most existing trees are still alive after the fires.

Table 4 also shows that the fires do not affect the carbon stock of the understory vegetation of the above-ground biomass. Carbon stock on the understory vegetation tends to increase after the fires. This happens because ±1.5 years after the fires, understory vegetation has grown rapidly at that location, that could be larger in number than before the fires. Research on 2015 peatland fires in Jambi Province also shows that carbon stock of understory vegetation grows until it reaches 7.74 tons/ha after three years of fires (Hamzah, Napitupulu, & Muryunika, 2019). However, because of the small percentage of understory species on above-ground biomass, the increase of carbon stock on the pool is not significant against the total above-ground biomass.

B. Carbon Stock Loss on Litter

The changes in carbon stock on litter differ for each forest type. In secondary peat swamp forest (SPSF) and Bushes Swamp (BS), there is a decrease of carbon stocks of the litter, and adversely there is an increase in secondary dryland forest (SDF) and forest plantation (FP) as shown in Table 5. The accumulation of litter on the forest floor is coming from the deciduous leaves and twigs from the forest tree. The litter

Table 5. Carbon stock of the litter before and after fires on various forest types in South Sumatra

Forest type	Carbon stock of litter before fires (t/ha)	Carbon stock of litter after fires (t/ha)
SPSF	4.1 ± 1.1	2.4 ± 1.6
BS	4.0 ± 2.9	2.2 ± 1.6
SDF	2.5 ± 1.3	3.8 ± 1.0
FP	1.5 ± 0.2	3.4 ± 1.9

Remarks: SPSF= secondary peat swamp forest, BS = bushes swamp, SDF = secondary dryland forest, FP = forest plantation that existed before the fire were thought to have been burned so that the litter that existed after the fires was a litter that accumulated after the fires until the measurement.

In the secondary peat swamp forest (SPSF) and bushes swamp (BS), carbon stock of the litter before the fires is quite large, reaching 4.0–4.1 tons/ha. All of the litter burns in the fire, after which the accumulation of the litter occur again, but the amount does not reach the original amount. The opposite happens in forest plantation (FP) and secondary dryland forest (SDF), in both forest types there is an increase of carbon stock of the litter. This increase is thought to occur due to the decay of branches and twigs after burning. Most of the trees in both forest types are not dead, but tree parts, in the form of branch and twigs, have dried and decayed some time after burning. After the tree growth returns to normal, physiologically, the leaves and branches that are aging, will be the source of litter accumulation. Furthermore, many research indicates that carbon stock on litter does not have a significant contribution to total carbon stock in many forest types (Dibaba, Soromessa, & Workineh, 2019; Takahashi et al., 2010; Ullah & Al-Amin, 2012).

C. Carbon Loss of Deadwood

Carbon stock of deadwood (DW) generally decreased after fires, except in secondary peat swamp forest (Table 6). The most considerable carbon loss of deadwood occurs in secondary dryland forest, amounting to 31.4 t/ha or (76.2%) from that of before fires (41.2 t/ha). Most of the carbon loss occurs due to the burning of standing deadwood trees that before burning was 38.9 t/ha and declined to 5.8 t/ha after the fires. The second-largest carbon loss of deadwood occurs on bushes swamp, amounting to 11.2 t/ha or 61.20% from that of before fires.

In contrast to 3 other forest types, carbon stock of deadwood (DW) in secondary peat swamp forest has increased. This happens because, after the fires, the living trees at that location die and become standing deadwood (SDW) and fallen deadwood (FDW). Carbon stock of standing deadwood in secondary peat swamp forest increased by 3.2 t/ha or 47.06% from that of before fires, while fallen dead wood increased by 4.6 t/ha or 52.87%. Increase of carbon stock on deadwood after forest disturbance also happens in the humid tropical forest in Sabah, Malaysia, where live tree carbon storage decreased exponentially with increasing forest degradation 7–10 times after logging. In contrast, deadwood increased until it reached 50% of above-ground carbon stocks (Pfeifer et al., 2015).

D. Total Carbon Loss

Total carbon stock is the sum of carbon stock of above-ground biomass (AGB), carbon stock of litter, and carbon stock of deadwood (DW). The three-carbon pools are directly affected by the fires, thus becoming an important indicator in assessing the impact of fires on carbon dioxide (CO_2) emissions. The largest total carbon loss occurs in secondary peat swamp

Table 6. Carbon stock of deadwood before and after fires in various forest types in South Sumatra

Forest type	Carbon stock of dead wood before fires (t/ha)			Carbon stock of dead wood after fires (t/ha)		
	SDW	FDW	Total	SDW	FDW	Total
SPSF	3.6 ± 4.3	8.7 ± 6.4	12.3 ±5.8	6.8 ± 9.0	13.3 ± 6.0	20.1 ± 10.3
BS	17.0 ± 18.9	1.3 ± 1.3	18.3 ± 19.0	6.2 ± 7.4	0.8 ± 0.6	7.1 ± 7.6
SDF	38.9 ± 13.1	2.3 ± 0.7	41.2 ± 13.8	5.8 ± 8.1	4.1 ± 2.5	9.8 ± 10.6
FP	6.5 ± 9.6	0.1 ± 0.1	6.6 ± 8.5	0.8 ± 1.3	2.8 ± 3.0	3.6 ± 4.2

Remarks: SDW= standing dead wood, FDW= fallen dead wood, SPSF= secondary peat swamp forest, BS = bushes swamp, SDF = secondary dryland forest, FP = forest plantation

Table 7. Total carbon loss affect by fires on various forest types in South Sumatra

Forest type	Total carbon stock before fires (t/ha)	Total carbon stock after fires (t/ha)	Total carbon stock loss (t/ha)
SPSF	121.8 ± 57.7	27.6 ± 15.6	94.2 ± 51.4
BS	44.1 ± 21.4	30.6 ± 12.7	13.5 ± 23.2
SDF	119.2 ± 9.7	82.9 ± 8.7	36.3 ± 0.9
FP	27.6 ± 17.0	9.1 ± 5.7	18.5 ± 11.3

Remarks: SPSF= secondary peat swamp forest, BS= bushes swamp, SDF= secondary dryland forest, FP= forest plantation

Table 8. Carbon stock loss on each carbon pool affected by fires in various forest types in South Sumatra

Forest type	AGB (t/ha)			LTR	Deadwood			Total carbon
	WP	UV	Total		SDW	FDW	Total	
SPSF	101.8	-1.6	100.3	1.7	-3.2	-4.6	-7.8	94.2
BS	2.1	-1.8	0.4	1.9	10.7	0.5	11.3	13.5
SDF	6.8	-0.5	6.3	-1.4	33.2	-1.8	31.3	36.3
FP	15.9	1.4	17.3	-1.9	5.8	-2.8	3.0	18.5

Remarks: AGB= above ground biomass, WP= woody plants, UV= understory vegetation, LTR= litter, SDW= standing dead wood, FDW= fallen dead wood, SPSF= secondary peat swamp forest, BS= bushes swamp, SDF= secondary dryland forest, FP= forest plantation

forest, amounting of 94.2 t/ha (Table 7) which is equivalent to the emission of 345.4 t CO_2eq/ha. This result is confirmed by any research of the fire of 2015 in Indonesia, especially in South Sumatra. The estimated burned area in South Sumatra during El Nino was 422,718 ha, of which most of them (61.64%) occurred in peatland particularly in Musi Banyuasin District (Ardiansyah et al., 2017; Tata et al., 2017). Globally fires of 2015 in Indonesia contributed with the emission of 0.8 to 1.9 Gt CO_2eq (Ministry of Environment and Forestry, 2015) Similar result of carbon loss also occurred in Lenga Beech Forest, Patagonia, Argentina, with severely burned areas losing carbon stock of 90.7–104.6 ton/ha (Bertolin, Urretavizcaya, & Defosse, 2015).

Most of the carbon loss on secondary peat swamp forest is the result of the loss of above-ground biomass which burns out or turns into dead wood, so the carbon stock of deadwood increased after fires as shown in Table 8. Fire in peatland is one of the most critical environmental problems in South East Asia including Indonesia which undergone recurrent fires particularly in South Sumatra (Konecny et al., 2016; Kumar, Adelodun, Khan, Krisnawati, & Garcia-Menendez, 2020).

The second-largest emissions are the result of fires in secondary dryland forest, resulting in carbon loss of 36.3 t/ha, which is equivalent to emissions of 133.1 t CO_2eq/ha. In contrast to the secondary peat swamp forest, most of the carbon losses in the secondary dryland forest are the result of the burning of deadwood. Carbon loss in bushes swamp and forest plantation respectively are 18.5 t/ha and 13.5 t/ha or equivalent to the emission of 67.8 t CO_2eq/ha and 49.47 t CO_2eq/ha. In forest plantation, most of the emissions occur as the result of the loss of above-ground biomass. In this forest type, although the emissions are relatively small compared to other forest types, the fires result in substantial economic losses, since the above-ground biomass on this forest type is cultivated plant.

IV. CONCLUSION

Based on the analysis of the fire effect on the carbon stock losses in South Sumatra in 2015, it can be concluded that carbon loss varies across forest types. The most considerable carbon loss occurs on secondary peat swamp forest amounting to 94.2 t/ha or equivalent to emissions of 345 t CO_2eq/ha. The second-largest carbon loss occurs in secondary dryland forest amounting to 36.3 t/ha and then on forest plantation and bushes swamp, respectively amounting to 18.5 t/ha and 13.5 t/ha. In secondary peat swamp forest and forest plantation, the most significant carbon loss occurs on above-ground biomass pool. Still, in secondary dryland forest and bushes swamp, it happens on dead wood carbon pool.

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COMPARATIVE WOOD ANATOMICAL PROPERTIES OF GENUS SYZYGIUM (FAMILY MYRTACEAE) FROM MANIPUR, INDIA

Mahesh Wangkhem, Madhubala Sharma* and Chaman L. Sharma

Department of Forestry, North Eastern Regional Institute of Science & Technology, Nirjuli -791109, Itanagar, Arunachal Pradesh, India

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COMPARATIVE WOOD ANATOMICAL PROPERTIES OF GENUS SYZYGIUM (FAMILY MYRTACEAE) FROM MANIPUR, INDIA. *Syzygium* belongs to family Myrtaceae and comprises of mostly trees and a few shrubs. This paper studies the anatomical and physical characteristics of five *Syzygium* species, namely *Syzygium cumini*, *Syzygium fruticosum*, *Syzygium jambos*, *Syzygium nervosum* and *Syzygium praecox* and to see intra and inter-species variation among them. The wood samples were taken at breast-height from straight bole and uniform crowned trees. The present study showed that all the selected species shared common features like simple perforation plate, vestured inter-vessel pits, disjunctive ray parenchyma cells, diffuse, diffuse-in-aggregate, vasicentric, aliform and confluent types of axial parenchyma, diffuse-porous and indistinct *fruticosum* were observed. The vessels were mostly barrel-shaped with small or long tails at one or both ends in all species except tube-shaped in *S. jambos* and drum-shaped in *S. fruticosum*. Spiral thickenings were present in the tails of *S. nervosum* and *S. fruticosum*. Fibres were thin-walled and non-septate. Occasional septate fibres and vasicentric tracheids were present in *S. nervosum* and *S. jambos*. Crystals in the ray of *S. nervosum* and *S. fruticosum* and silica bodies in axial parenchyma of *S. jambos* were observed. The fibre percentage and wood density were maximum in *S. jambos*, whereas moisture content was minimum in *S. jambos*. Principal Component Analysis revealed a close relationship among all species. Therefore, the qualitative characteristics and all quantitative anatomical characteristics can be used for reliable identification of *Syzygium* species.

Keywords: *Syzygium* species, anatomical characteristics, wood density, moisture content

PERBANDINGAN KARAKTERISTIK ANATOMI KAYU GENUS SYZYGIUM (FAMILY MYRTACEAE) YANG BERASAL DARI MANIPUR, INDIA. Syzygium merupakan Family Myrtaceae yang sebagian besar terdiri dari pohon dan semak. Tujuan penelitian ini adalah untuk mempelajari karakteristik anatomi dan sifat fisik dari lima spesies Syzygium, yaitu Syzygium cumini, Syzygium fruticosum, Syzygium jambos, Syzygium nervosum, *dan* Syzygium praecox *dan untuk melihat variasi intra dan antar spesies. Contoh uji diambil dari batang lurus setinggi dada dengan kondisi pohon yang bertajuk relatif seragam. Hasil penelitian menunjukkan bahwa karakteristik anatomi semua spesies yang dipelajari berciri relatif sama, yaitu bidang perforasi sederhana, noktah antar-pembuluh berumbai, sel parenkim jari-jari disjungtif, difus, difus-in-agregat, vasicentric, aliform dan konfluen aksial parenkima, difus porus dan frusicosum tidak jelas. Pembuluh sebagian besar berbentuk silinder dengan ekor kecil atau panjang di satu atau kedua ujungnya di semua spesies kecuali berbentuk tabung di* S. jambos *dan berbentuk silinder di* S. fruticosum. *Penebalan spiral dijumpai di bagian ekor* S. nervosum *dan* S. fruticosum. *Serat berdinding tipis dan tidak bersekat. Serabut bersekat sesekali dijumpai pada trakeid vasicentric jenis* S. nervosum *dan* S. jambos. *Sel kristal dalam jari-jari dijumpai pada jenis* S. nervosum *dan* S. fruticosum *dan badan silika di parenkima aksial jenis* S. jambos. *Persentase serat dan kepadatan kayu paling besar tercatat di* S. jambos, *sedangkan kadar air minimum tercatat di contoh uji* S. jambos. *Analisis komponen utama mengungkapkan hubungan yang erat di antara semua jenis. Oleh karena itu, karakteristik kualitatif bersama dengan karakteristik anatomi kuantitatif dapat digunakan sebagai dasar identifikasi jenis Syzygium.*

Kata kunci: spesies Syzygium, karakteristik anatomi, kepadatan kayu, kadar air

* Corresponding author: mbs_madhu@yahoo.co.in

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I. INTRODUCTION

The word *Syzygium* is derived from a Greek word 'syzgios" which means the presence of "paired/coupled" branches and leaves (Janick & Paull, 2008). It is one of the most abundant genera in family Myrtaceae with 1200 species. It is distributed from Africa eastwards to the Hawaiian Island, India, Southern China southwards to Australia and New Zealand (Parnell et al., 2007; Govaerts et al., 2008; Ahmad et al., 2016; Christenhusz et al., 2017). It ranks on 16th position among the 57 most abundant genera of flowering plants (Govaerts et al., 2018). Most of the workers have considered both *Syzygium* and *Eugenia* under genus *Eugenia* (Henderson, 1949) as there is no distinction between their morphological characters. Ingle and Dadswell (1953) divided *Eugenia* into two sections based on anatomical structure – '*Eugenia* A' is comprised of the species having similarity with the new world species and '*Eugenia* B' has *Syzygium* and other *Eugenia* species which are similar in their anatomy. The timbers of *Eugenia* A are characterized by the presence of vasicentric tracheids, solitary pores, apotracheal parenchyma, vessel ray pitting small and similar to inter vessel pits. The timbers of *Eugenia* B are characterized by absence of vasicentric tracheids, presence of multiple pores, paratracheal parenchyma, simple to scalariform vessel ray pitting. This grouping was also supported by Chattaway (1959) who observed substantial differences in bark structure between two groups. The separation of *Eugenia* and *Syzygium* as different lineage by Schimid (1972) is further confirmed with molecular studies by several workers (Wilson et al., 2001, 2005; Biffin et al., 2010).

In India, Genus *Syzygium* is represented by 91 species, of which most are trees and few shrubs (Arisdason & Lakshminarasimhan, 2017). *Syzygium aromaticum* is the essential spices with high commercial value. Species like *Syzygium cumini*, *Syzygium jambos* are being cultivated in several parts of India for their fruits. From timber point of view, *Syzygium cumini* is the most important species. Several other species like *S. calophyllifolium*, S. *cerasoides*, *S. cavaran*, *S. densiflorum*, *S. grande* etc. also have good timber value and are being used for construction, furniture, flooring, telegraph poles, side props in mine shafts and galleries, railway sleepers, bottom boards of railway carriages, implements, packaging case, fibreboard, and veneer and plywood.

The anatomical characteristics of wood are valuable storehouse for environmental studies (Fonti et al., 2010) to determine additional and new ecological information and to see the relationship between tree growth and environmental factors. They also help to resolve taxonomical problems to separate the different species. Since there is no information on wood anatomical characteristics of selected *Syzygium* species, therefore, the present study was carried out (a) to study anatomical and physical features of *Syzygium* species and (b) to study intra- and inter-species variation in these characteristics.

II. MATERIAL AND METHOD

A. Study Site

Five straight trees with uniform crown and no visible defects of each species were randomly selected from Kakching and Imphal West districts of Manipur, India. The geographical coordinates, height and diameter of selected species were given in (Table 1).

B. Methods

Wood samples of 5 cm × 5 cm × 4 cm size at breast height were taken. The wood samples were packed in polythene bags and brought to the laboratory for further processing. Collected samples were cut into small blocks of 2 cm^3 size. They were fixed in FAA (Formalin-aceto-alcohol) for 24–48 hrs and preserved in 50% alcohol for anatomical studies. These blocks were cut in 3 planes namely Cross Section (C. S.), Tangential Longitudinal Section (T. L. S.) and Radial Longitudinal Section (R. L. S.) with the help of a sliding microtome (Leica SM 2000R). Standard methods were followed to prepare permanent slides.

Table 1. List of *Syzygium* species collected from different sites of Manipur

Species	Latitude & Longitude	Height (m)	Diameter (cm)	Locality
S. cumini	24°29.938' N - 24°47.829' N 93°58.084'E - 93°55.463' E	5.2–8	32.48–38.85	Mahadevching, Kakching Sagolband, Imphal west
S. fruticosum	24°29.664' N - 24°29.679' N 93°57.860' E - 93°57.795' E	6.5–9.8	36–49	Mahadevching, Kakching
S. jambos	24°30.107' N - 24°30.329' N 93°58.737' E - 93°58.384' E	4.9–8.4	13.69–15.29	Chumnang, Kakching
S. nervosum	24˚43'12"N - 24˚44'09"N 93˚55'47"E - 93˚54'49"E	5.5–6.1	19.41–38.83	Lilong chajing, Imphal
S. praecox	24°29.938' N - 24°30.784' N 93°58.074' E - 93°58.116' E	5.8–7	19.10–23.57	Ashram ching, Kakching

Thin matchstick-size of wood was taken from the radial side of each sample of selected species and was macerated with Franklin's solution at 60˚C for 24 hours till they become soft and white. The macerated material was washed with distilled water 2–3 times and gently shaken to get a fluffy mass of fibres. 2–3 drops of safranine were added, and temporary slides were prepared by using 50% glycerol. The dimensions of anatomical parameters of vessels, fibres and rays were taken with the help of Scopeimage 9.0 software at different magnifications. For each sample of selected species, 30 random fibres, vessels and rays were chosen for measurement of their various parameters. Ten fields per sample of each species were randomly selected for counting the number of vessels per mm^2 and ray per mm in cross-section. Thus, a total of 250 fields were observed for both parameters. Fibre, vessel, parenchyma and ray proportion were determined on cross-section by selecting ten fields.

The anatomical descriptions of species were given by following IAWA list of microscopic features for hardwoods identification (Wheeler et al., 1989). Different vessel shapes were identified as given by Helmling et al. (2018). The photomicrographs of selected species were taken with the help of image analysis system at different magnifications for their anatomical features.

Water displacement method (Smith, 1955) was used to determine the wood density. Moisture content was determined, as mentioned by Panshin and deZeeuw (1980).

C. Analysis

The data were statistically analysed by using SPSS 16 software. One way ANOVA followed by Tukey's test was performed to compare the differences in anatomical characteristics among species.

III. RESULT AND DISCUSSION

A. *Syzygium cumini* (L.) Skeels. (Figure 1A-1F; Figure 6A-6D)

General features – Indistinct heartwood and sapwood; wood colour ranges from pale grey or greyish brown in the outermost region to dark brown or reddish-brown towards the centre; wood is moderately hard to hard and moderately dense to heavy; grain generally shallowly interlocked, sometimes wavy; medium to coarse-textured.

Anatomical features – A semi-ring porous, diffuse-porous wood.

Growth rings – Both distinct and indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, circular in outline, barrel shape without the tail, with very long or small tail at one and/ or both ends, 500–1200 µm (868.83 ± 147.66 µm) in length, 105.77–193.69 µm (146.02 ± 17.18 µm) in diameter, vessel frequency 6–20

(11±3) per mm^2, simple perforation plate, inter-vessel pit alternate, vestured, small to medium 6.87–9.62 µm (8.2±0.6 µm) in size, vessel ray pits with much reduce borders to apparently simple: pits horizontal (scalariform, gash like) to vertical (palisade), tyloses present, vessel percentage 17.45%.

Fibres – Thin-walled, 1050–2300 µm (1766.83±222.13 µm) long, 18.28–35.89 µm (25.13±3.64 µm) and 11.08–28.05 µm (18.62±3.32 µm) in diameter and lumen diameter, 2.19–6.37 µm (3.26 ± 0.66 µm) in wall thickness, fibre percentage 40.36%.

Parenchyma – Mostly scanty, diffuse, diffuse-in-aggregate and confluent, parenchyma strand 4-12 cells, vestured pits present, parenchyma percentage 14.55 %.

Ray – Uniseriate, biseriate and multiseriate, mean ray height and ray width 352.52–944.07 µm (632.08±120.59 µm) and 30–77.56 µm (49.98±8.79 µm), 1–3 cells wide, rays both homocellular and heterocellular, all homocellular rays of upright/square cells, heterocellular rays of body ray cells procumbent with one row of upright and/or marginal square cells, rays 5–10 (8±2) per mm, disjunctive ray parenchyma cells present, ray percentage 27.64%.

B. *Syzygium fruticosum* DC. (Figure 2A-2F; Figure 6E-6H)

General features – Indistinct heartwood and sapwood, wood pale grey to reddish-brown, moderately hard and moderately heavy; wavy rarely straight grain.

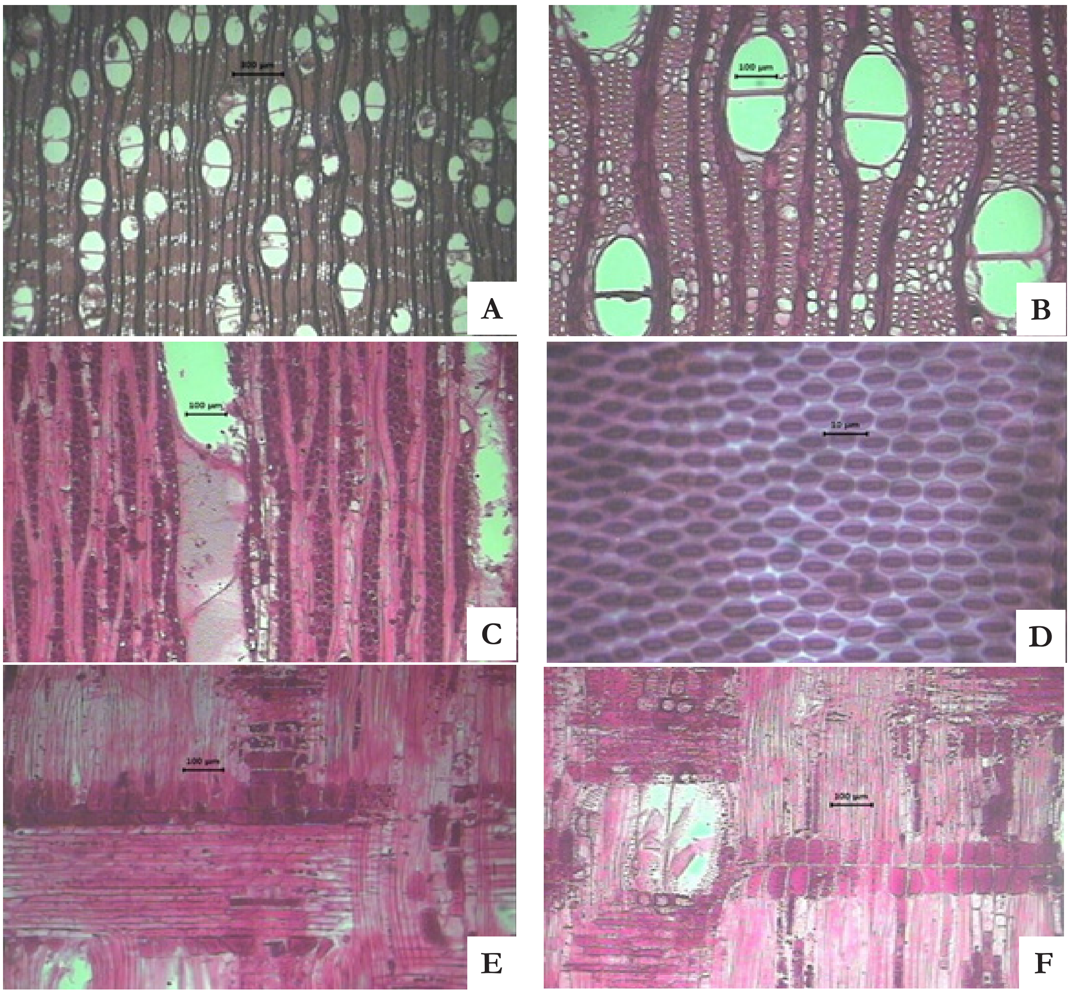

Figure 1. *Syzygium cumini*: C. S. - Wood diffuse-porous, parenchyma diffuse and confluent type (A & B); T. L. S. - Rays uniseriate, biseriate and multiseriate (C), vestured intervessel pits (D); R. L. S. - Heterocellular ray of procumbent and upright and/or marginal square cells (E); homocellular ray of upright/square cells (F)

Anatomical features – A semi-ring porous, diffuse-porous wood.

Growth rings – Both distinct and indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, oval in outline, drum and tube shape with spiral thickening in small and pointed tails, 275–925 µm (526.50±124.327 µm) in length, 63.19–152.47 µm (113.76±17.63 µm) in diameter, vessel frequency 6–10 (13±3) per mm^2, simple perforation plate, inter-vessel pit alternate, vestured, small to medium 7.83–10.85 µm (9.30 ± 0.67 µm) in size, vessel ray pits with much reduce border to apparently simple pits horizontal (scalariform, gash like) to vertical (palisade), tyloses present, vessel percentage 22.91%.

Fibres – Thin-walled, 900–1875 µm (1286.83±186.96 µm) long, 15.66–34.34 µm (23.30±3.04 µm) and 10.44–27.61 µm (16.66±2.65 µm) in diameter and lumen diameter, 2.06–5.22 µm (3.32±0.61 µm) in wall thickness, septate fibres present, fibre percentage 30.91%.

Parenchyma – Diffuse, diffuse-in-aggregate, aliform and confluent, parenchyma strand 4–12 cells, bordered pits present, parenchyma percentage 29.09%.

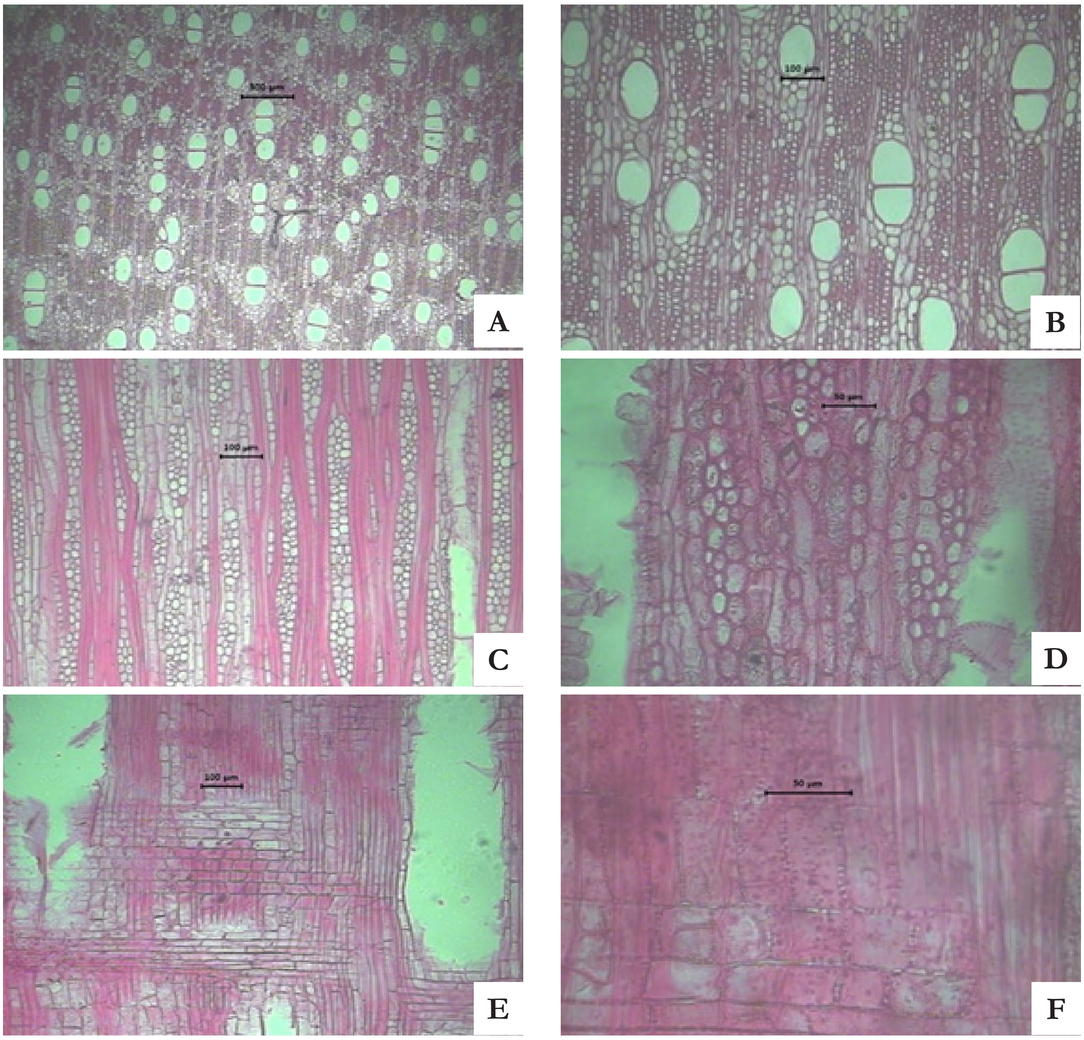

Figure 2. *Syzygium fruticosum*: C. S. - Wood diffuse-porous, vessels mostly solitary in radial multiple of 2 – 4, parenchyma diffuse, diffuse-in-aggregate, confluent type (A & B); T. L. S. - Rays multiseriate, parenchyma strand 4–12 celled (C), crystals in ray and parenchyma cell (D); R. L. S. - Heterocellular ray of procumbent and upright and/or marginal square cells (E); Disjunctive ray parenchyma cell walls (F)

Ray – Mostly multiseriate, mean ray height and ray width 226.09–946.21 µm (501.60±158.41 µm) and 28.02–68.90 µm (47.71±8.28 µm), 1–3 cells wide, rays both homocellular and heterocellular, all homocellular rays of square cells, heterocellular rays are consisting of body ray cells procumbent with 2–4 rows of upright and/or marginal square cells, rays 4–11 (7±2) per mm, disjunctive ray parenchyma cells present, ray percentage 17.09%.

Mineral inclusions – Crystals and crystal sand present in ray and parenchyma, black streaks present among fibres.

C. *Syzygium jambos* (L.) Alston (Figure 3A-3F; Figure 6I-6L)

General features – Indistinct heartwood and sapwood, reddish grey to brown, wood slightly soft, moderately heavy, with a reasonably regular wavy grain.

Anatomical features – A diffuse-porous wood.

Growth rings – Both distinct and indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, clusters, circular in outline, tube shape with short/long tail at one or both ends, 475–1700 µm (892±186.66 µm) in length, 61.81–105.78 µm (83.85 ± 8.62 µm) in diameter, vessel frequency

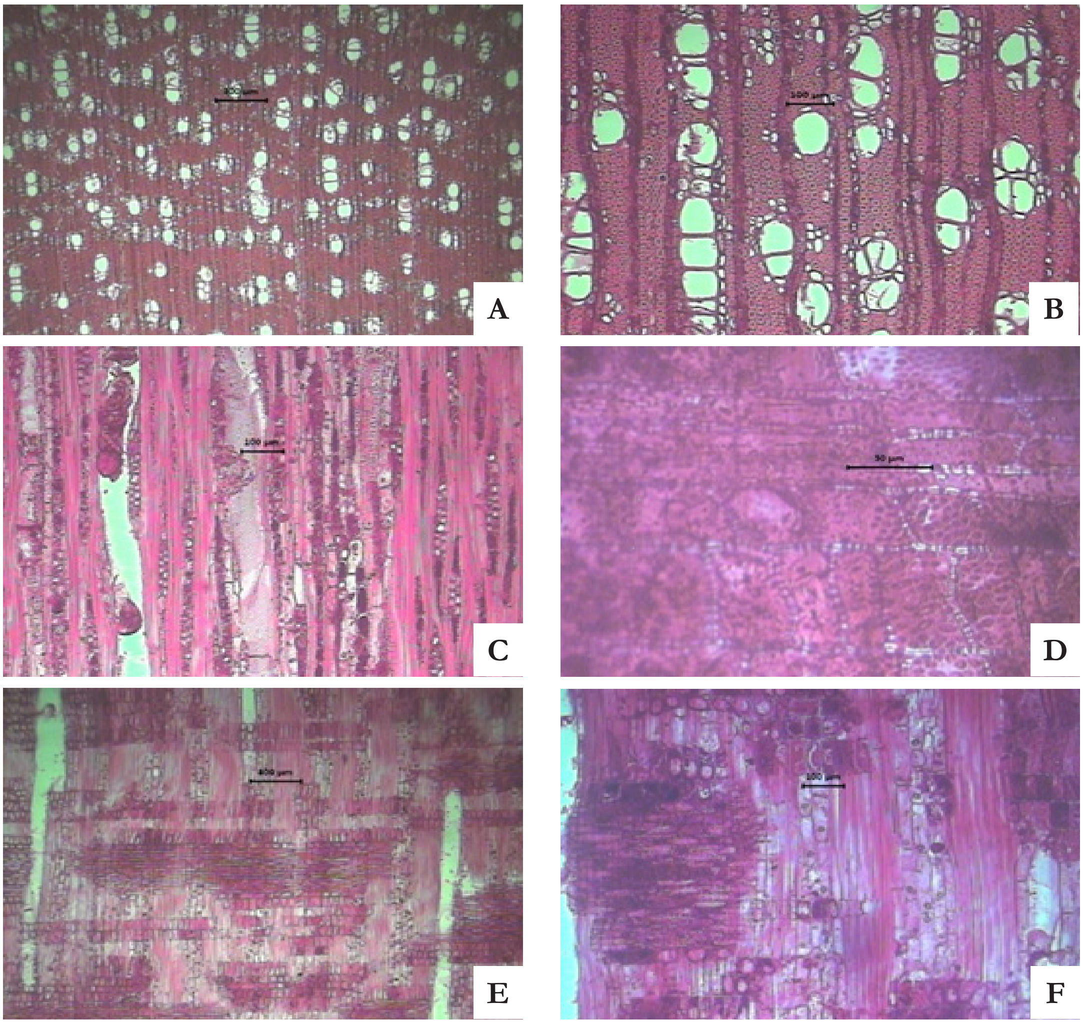

Figure 3. *Syzygium jambos*: C. S. - Wood diffuse-porous, vessels mostly solitary in radial multiple of 2–4 Parenchyma diffuse, diffuse-in-aggregate, aliform type (A & B); T. L. S. - Rays multiseriate, tyloses parenchyma strand 2–13 celled (C); R.L.S. - Vessel-ray pits with much-reduced border to simple pits rounded (D); heterocellular rays of procumbent and upright and/or marginal square cells (E), silica bodies in axial parenchyma cells (F)

14–30 (21±4) per mm^2, simple perforation plate, inter-vessel pit alternate, vestured, small-medium 6.87–8.93 µm (7.72±0.45 µm) in size, vessel ray pits with much reduce borders to apparently simple: pits rounded, tyloses present, vessel percentage 14.91%.

Fibres – Thin - thick-walled, 1175–2425 µm (1657.83±237.30 µm) long, 17.52–28.81 µm (22.20±2.06 µm) and 7.20–17.35 µm (11.62±1.82 µm) in diameter and lumen diameter, 3.35–7.92 µm (5.29±1.02 µm) in wall thickness, vascicentric tracheid present, fibre percentage 44%.

Parenchyma – Diffuse, diffuse-in-aggregate, aliform, confluent and banded, parenchyma strand 4–12 cells, parenchyma percentage 20.36%.

Ray – Uniseriate and biseriate, mean ray height and ray width 369.16–870.23 µm (574.13±106.07 µm) and 33.08–56.90 µm (40.11±4.44 µm), 1–3 cells wide, rays both homocellular and heterocellular. Homocellular rays of upright and/or square cells, heterocellular rays consisting of body ray cells procumbent with 1–2 rows of upright and/or marginal square cells, rays 7–14 (10±2) per mm, disjunctive ray parenchyma cells present, ray percentage 20.73%.

Mineral inclusions – Silica bodies present in the parenchyma.

D. *Syzygium nervosum* DC. (Figure 4A-4F; Figure 6M-6P)

General features – Indistinct heartwood, wood reddish grey, hard, rough; moderately heavy – heavy; wavy grain to reasonably straight grain.

Anatomical features – A diffuse-porous wood.

Growth rings – Indistinct.

Vessels – Mostly solitary, in radial multiple of 2–3, circular in outline, barrel-shaped without and with spiral thickenings in very long/ small tails at one or both ends, 375–825 µm (557.67±114.29 µm) in length, 103.02–181.32 µm (135.15±16.42 µm) in diameter, vessel frequency 11–21 (16±3) per mm^2, simple perforation plate, inter-vessel pit alternate and also scalariform, vestured, small-medium 7.08–10.27 µm (8.82±0.65 µm) in size, vessel ray pits with much reduce borders to simple: pits rounded, tyloses present, vessel percentage 20.36%.

Fibres – Thin-walled, 1025–1850 µm (1404.83±150.88 µm) long, 18.85–36.05 µm (24.04±3.21 µm) and 12.19–27.79 µm (17.91±2.96 µm) in diameter and lumen diameter, 2.21–4.50 µm (3.07±0.47 µm) in wall thickness, septate fibres present, fibre percentage 38.91%.

Parenchyma – Scanty, vasicentric, diffuse, diffuse-in-aggregate and aliform, parenchyma strands 2-13 cells, vestured pits present in the parenchyma, parenchyma percentage 21.82%.

Ray – Multiseriate, mean ray height and ray width 393.01–843.77 µm (547.81±104.36 µm) and 30.34–71.48 µm (46.84±8.53 µm), rays both homocellular and heterocellular, all homocellular rays of square cells, heterocellular rays consisting of body ray cells of procumbent with one row of upright and/or marginal square cells, rays 4–9 (6±1) per mm, disjunctive ray parenchyma cells present, ray percentage 18.91%.

Mineral inclusions – Crystal in fibre and parenchyma, black streaks present among fibres.

E. *Syzygium praecox* (Roxb.) Rathakr. & N.C.Nair (Figure 5A-5F; Figure 6Q-6T)

General features – Heartwood and sapwood not clearly demarcated, wood pale grey or greyish brown in the outermost region and gradually grading into dark brown or reddish-brown towards the centre, moderately hard to hard and moderately heavy to heavy, usually interlocked sometimes wavy grains.

Anatomical features – A diffuse-porous wood.

Growth rings – Indistinct.

Vessels – Mostly solitary in radial multiple of 2–4, oval or circular in outline, barrel-shaped without and with very long or small tail at one or both ends, 325–975 µm (652.50±134.23 µm) in length, 61.81–204.67 µm (112.58±29.89 µm) in diameter, vessel frequency 10–22 (15±3) per

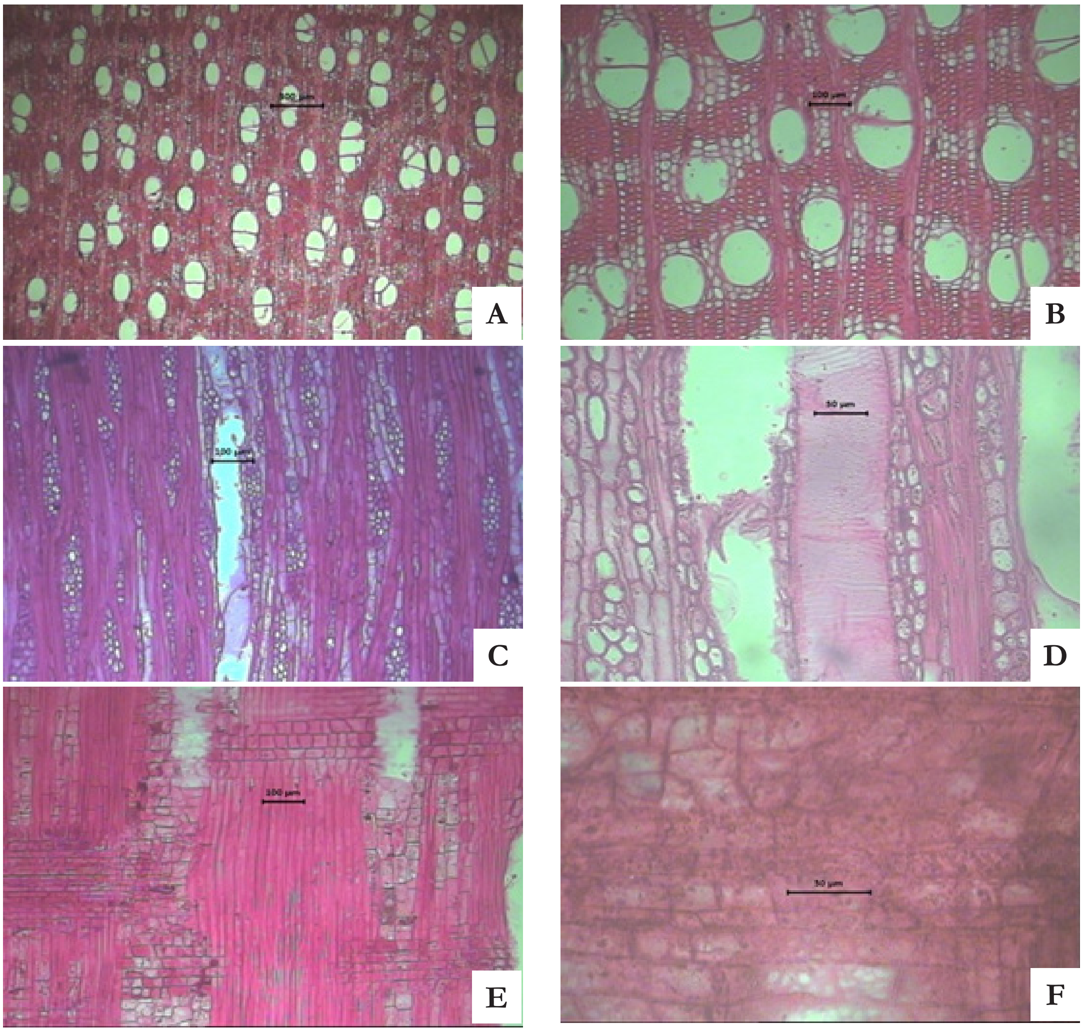

Figure 4. *Syzygium nervosum*: C. S. - Wood diffuse-porous, vessels mostly solitary and in radial multiple of 2–3, banded Parenchyma (A & B); T. L. S. - Rays uniseriate, biseriate and multiseriate; parenchyma strand 2–13 celled, crystals in fibre and parenchyma cells (C); scalariform vestured intervessel pits (D); R. L. S. - With a homocellular ray of square cells and heterocellular rays of procumbent body ray cells with 1 row of upright and/or marginal square cells, the crystal in fibre and parenchyma cells (E) and Vessel-ray pits with much-reduced border to simple pits rounded pits (F)

mm^2, simple perforation plate, inter-vessel pit alternate, vestured, small-medium 6.05–8.79 μm (7.61±0.51 μm) in size, vessel ray pits with much reduce borders to apparently simple: pits rounded, tyloses present, vessel percentage 16.73%.

Fibres – Thin-walled, 975–1875 μm (1362.5±179.5 μm) long, 16.07–26.59 μm (20.76±2.07 μm) and 10.53–19.39 μm (14.39±1.95 μm) in diameter and lumen diameter, 1.99–4.76 μm (3.18±0.64 μm) in wall thickness, fibre percentage 38.36%.

Parenchyma – Diffuse, diffuse-in-aggregate, vasicentric, confluent and banded, 4–16 cells per parenchyma strand, vestured pits present in the parenchyma, parenchyma percentage 26.55%.

Ray – Uniseriate, biseriate and multiseriate, mean ray height and ray width 348.60–737.42 μm (533.75±80.13 μm) and 25.03–52.36 μm (36.46±5.45 μm), rays both homocellular and heterocellular, all homocellular rays of upright and/or square cells, heterocellular rays consisting of body ray cells procumbent with

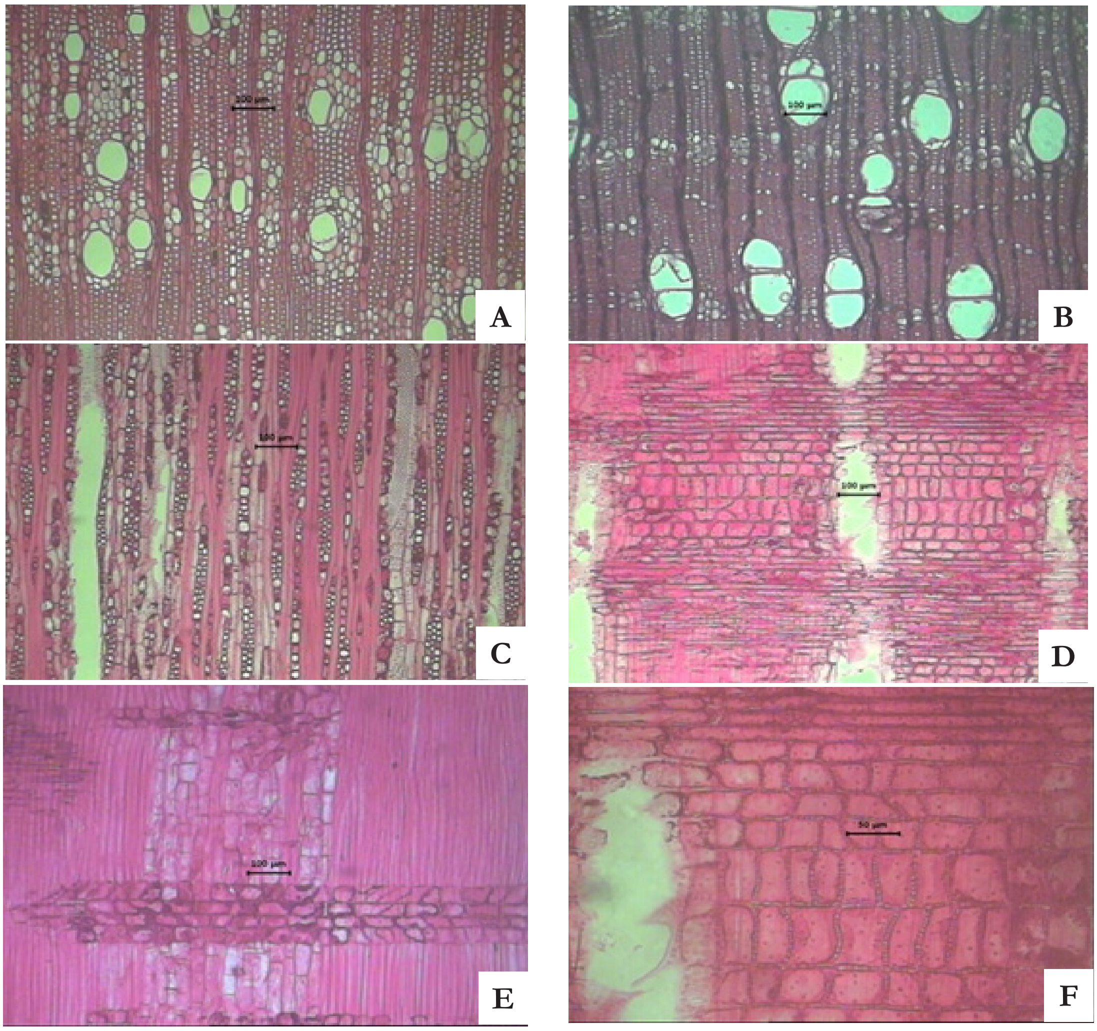

Figure 5. *Syzygium praecox*: C. S. - Wood diffuse-porous, vessels mostly solitary and in radial multiple of 2–4, diffuse, diffuse-in-aggregate and confluent type of parenchyma (A & B); T. L. S. - Rays uniseriate, biseriate and multiseriate, parenchyma strand 4–16 celled (C); R. L. S. - Heterocellular ray with procumbent square and upright cells mixed throughout the ray (D), a homocellular ray of upright and/or square cells (E); disjunctive ray parenchyma cell walls (F)

mostly 2–4 rows of upright and/or marginal square cells, rays 6–15 (9±2) per mm, disjunctive ray parenchyma cells present, ray percentage 18.18%.

The results given in Table 2 show that the anatomical parameters exhibiting significant variation within species were vessel diameter in *S. cumini* and *S. jambos*, vessel length and vessel frequency in *S. nervosum*, fibre wall thickness in *S. cumini*, fibre diameter in *S. jambos*, fibre lumen diameter, ray height and width in *S. praecox*, number of cells in parenchyma strand and ray per mm in all species.

The vessel, fibre and ray characteristics exhibited significant variation among species except for several cells in parenchyma strand. Vessels were significantly longer in *S. cumini* and *S. jambos* than other species. Vessel diameter was substantially larger in *S. cumini* whereas inter-vessel pits were larger in *S. fruticosum*. Vessel frequency was significantly more in *S. jambos* than other species. Fibre length, fibre diameter and fibre lumen diameter were substantially higher in *S. cumini*, and fibre wall thickness was more in S. jambos than other species. Ray heights were significantly longer in *S. cumini* and

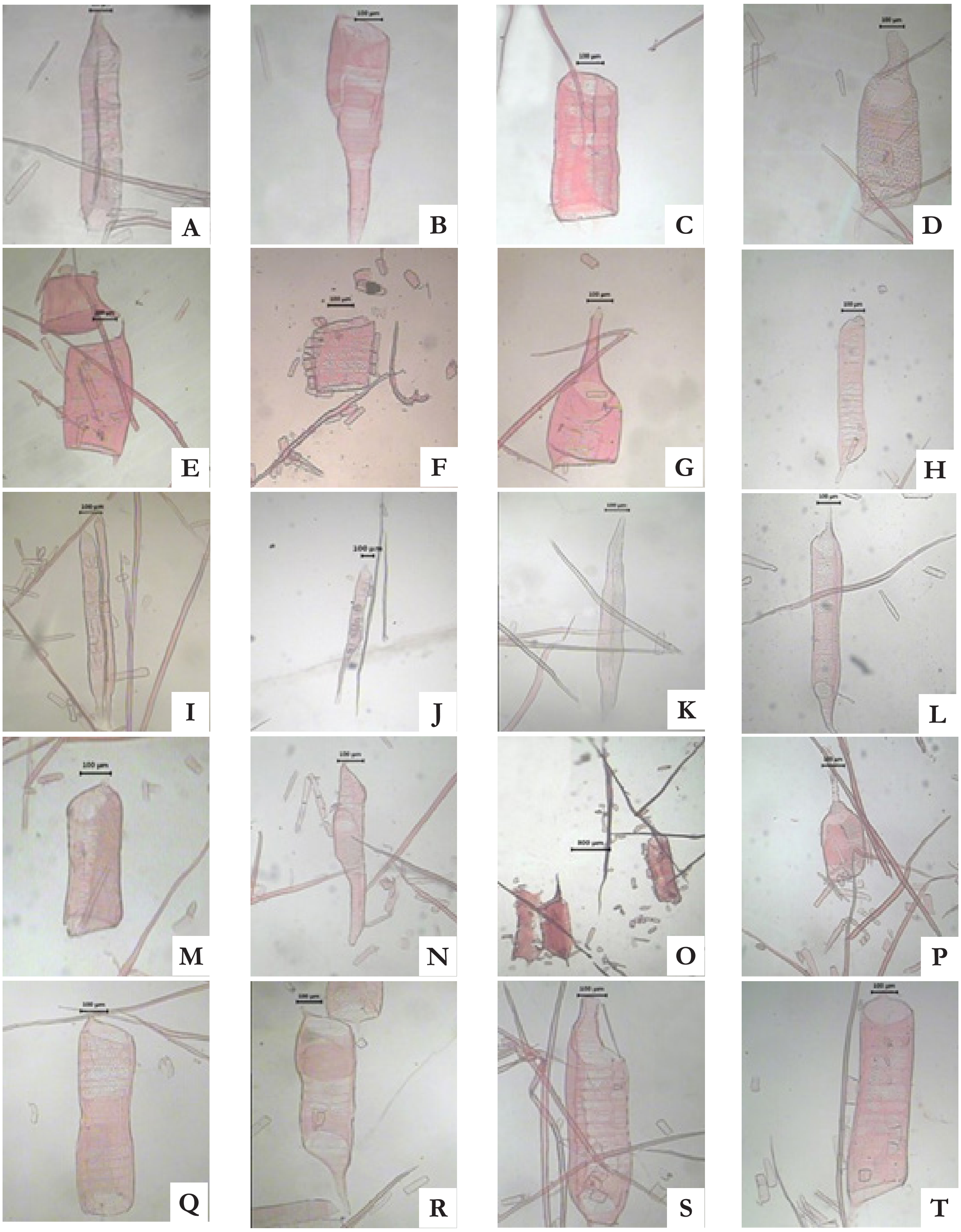

Figure 6. Vessel elements shape: *Syzygium cumini* – Tube shaped (A), barrel-shaped with and without tails (B - D); *Syzygium fruticosum* – Barrel-shaped with a small and pointed tail (E - F), spiral thickenings in the tail (G), tube-shaped (H); *Syzygium jambos* – Vasicentric tracheid with the vessel (I), tube-shaped vessels (J - L); *Syzygium nervosum* – Barrel-shaped with small, pointed and long-tail (M - O), spiral thickenings in the tail (P); *Syzygium praecox*- Barrel-shaped vessels with a small and long-tail (Q – T)

Table 2. Analysis of variance of anatomical characteristics within the selected *Syzygium* species

Parameters	*Syzygium cumini*	*Syzygium fruticosum*	*Syzygium jambos*	*Syzygium nervosum*	*Syzygium praecox*
			(F value)		
Vessel length	8.809**	13.337**	7.405**	2.216^{ns}	26.323**
Vessel diameter	2.003^{ns}	22.055**	2.268^{ns}	18.078**	115.225**
Vessel frequency	3.706*	15.869**	3.282*	1.220^{ns}	5.025**
Inter vessel pit size	28.636*	5.866**	2.259^{ns}	10.014**	7.774**
Fibre length	3.465*	14.768**	16.208**	2.773*	20.630*
Fibre diameter	13.921**	7.397**	1.248^{ns}	8.726**	4.649**
Fibre lumen diameter	15.550**	11.003**	8.098**	6.276**	1.193^{ns}
Fibre wall thickness	1.249^{ns}	5.571**	16.253**	9.777**	24.789**
Ray height	8.397**	16.364**	13.622**	3.847**	1.424^{ns}
Ray width	15.196**	11.799**	3.707*	36.183**	15.811**
Ray frequency	1.911^{ns}	2.122^{ns}	1.826^{ns}	0.785^{ns}	4.986**

Remarks: The levels of significance used are: ns = Not-significant, * = Significant at $P \leq 0.05$ level, ** = Highly significant at $P \leq 0.01$ level

Table 3. Anatomical characteristics variation among *Syzygium* species

Parameters	*Syzygium cumini*	*Syzygium fruticosum*	*Syzygium jambos*	*Syzygium nervosum*	*Syzygium praecox*
			(Mean± SD)		
Vessel length (μm)	868.83 ± 147.66^{c}	526.50±124.327^{a}	892.00±186.66^{c}	557.67±114.29^{a}	652.50 ±134.23^{b}
Vessel diameter (μm)	146.02 ± 17.18^{d}	113.76 ± 17.63^{b}	83.85 ± 8.62^{a}	135.15 ± 16.42^{c}	112.58 ± 29.89^{b}
Inter vessel pit size (μm)	8.20 ± 0.60^{b}	9.30 ± 0.67^{d}	7.72 ± 0.45^{a}	8.82 ± 0.65^{c}	7.61 ± 0.51^{a}
Vessel frequency (no./mm^2)	11.00 ± 3.00^{a}	13.00 ± 3.00^{a}	21.00 ± 4.00^{c}	16.00 ± 3.00^{b}	15.00 ± 3.00^{b}
Fibre length (μm)	1766.83 ± 222.13^{d}	1286.83±186.96^{a}	1657.83±237.30^{c}	1404.83±150.88^{b}	1362.50±179.50^{bc}
Fibre diameter (μm)	25.13 ± 3.64^{d}	23.30 ± 3.04^{bc}	22.20 ± 2.06^{b}	24.04 ± 3.21^{cd}	20.76 ± 2.07^{a}
Fibre lumen diameter (μm)	18.62 ± 3.32^{d}	16.66 ± 2.65^{c}	11.62 ± 1.82^{a}	17.91 ± 2.96^{d}	14.39 ± 1.95^{b}
Fibre wall thickness (μm)	3.26 ± 0.66^{a}	3.32 ± 0.61^{a}	5.29 ± 1.02^{b}	3.07 ± 0.47^{a}	3.18 ± 0.64^{a}
Ray height (μm)	632.08 ± 120.59^{c}	501.60 ±158.41^{a}	574.13 ±106.07^{b}	547.81±104.36^{bc}	533.75 ± 80.13^{ab}
Ray width (μm)	49.98 ± 8.79^{d}	47.71 ± 8.28^{cd}	40.11 ± 4.44^{b}	46.84 ± 8.53^{c}	36.46 ± 5.45^{a}
Ray frequency	8 ± 2^{b}	7 ± 2^{ab}	10 ± 2^{c}	6 ± 1^{a}	9 ± 2^{c}

Remarks: Values with the same letter in the same row are not significantly different at the 0.05 probability level

S. nervosum. On the other hand, *S. cumini* and *S. fruticosum* had wider rays as compared to other species. The number of rays per mm was higher in *S. jambos* than other species (Table 3).

The maximum fibre percentage was in *S. jambos* (44%) and the minimum in *S. fruticosum* (30.91%). Likewise, highest vessel percentage, ray percentage and parenchyma percentage were observed in *S. fruticosum* (22.91%), *S. cumini* (27.64%) and *S. fruticosum* (29.09%) respectively

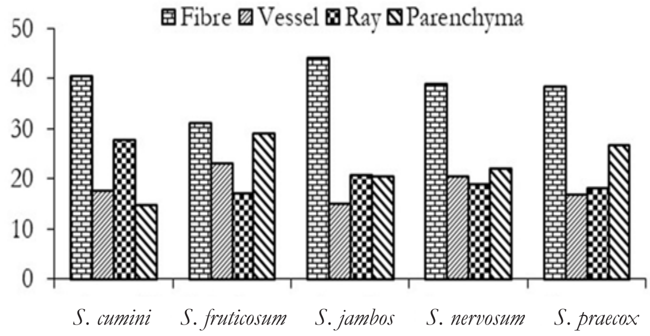

Figure 7. Tissue percentage of the selected *Syzygium* species

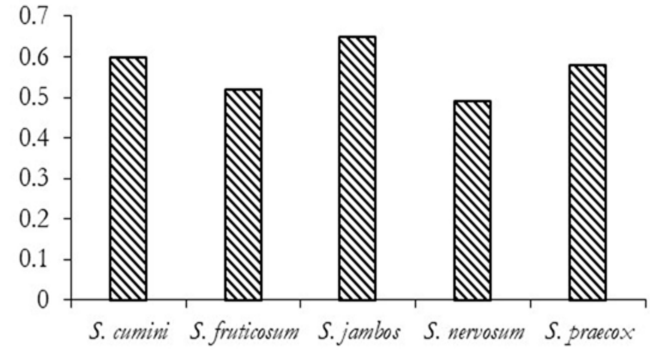

Figure 8. Wood density of selected *Syzygium* species

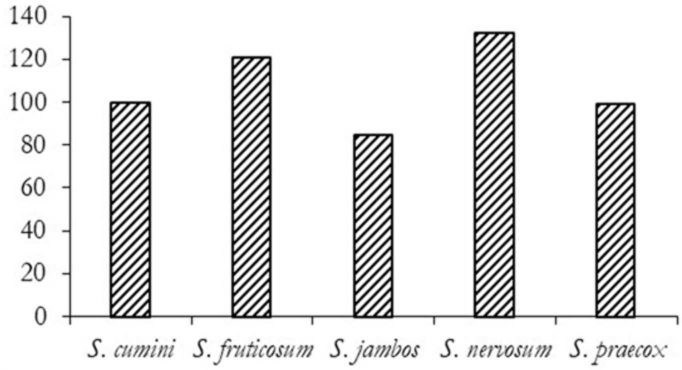

Figure 9. The moisture content of selected *Syzygium* species

(Figure 7). The results presented in Figure 10 revealed that *S. cumini* was closely related to *S. praecox*. There was a more close relationship between *S. fruticosum* and *S. nervosum*. Though *S. jambos* was also in the same axis, but it forms a separate group.

The result given in Figures 8 showed maximum wood density in *S. jambos* and minimum in *S. nervosiigum*. On the contrary to it, the maximum wood moisture content was in *S. nervosum* and minimum in *S. jambos* (Figure 9).

The wood structure in Syzygium species is uniform as reported in other genera of family Myrtaceae (Dias-Leme et al., 1995). All the selected species were diffuse-porous with indistinct rings except both diffuse-porous and semi-ring porous in *S. cumini* and *S. fruticosum*. The vessels were mostly barrel-shaped with small or long tails at one or both ends in all species except tube-shaped in *S. jambos* and

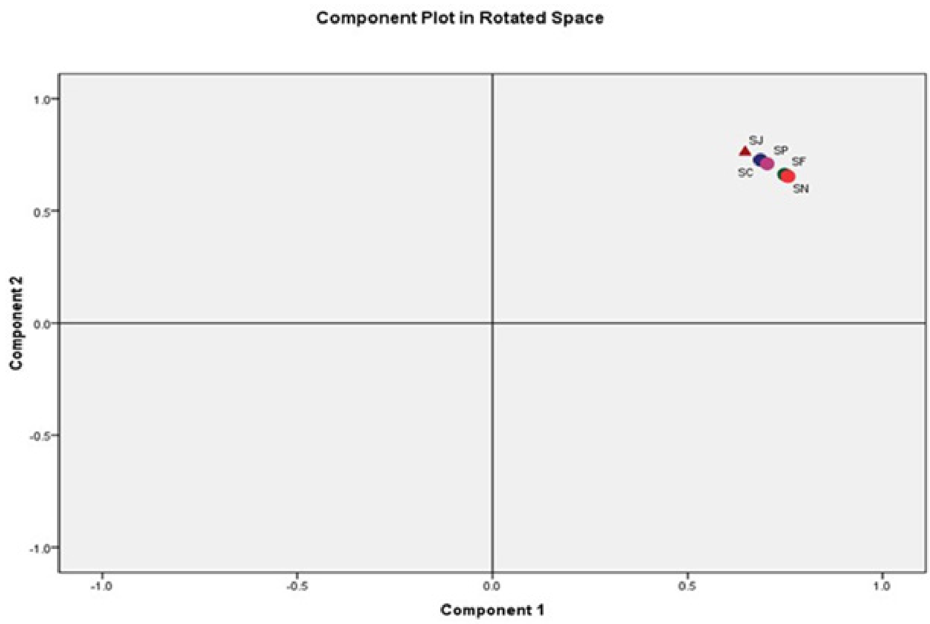

Figure 10. Scattered plot for principal component analysis of selected *Syzygium* species

drum-shaped in *S. fruticosum*. Spiral thickenings were present in the tails of *S. nervosum* and *S. fruticosum*. Presence of spiral thickenings in vessel elements and simple perforation plate, small to medium-sized vestured pits and tyloses were common features in all selected species. Similar observations are reported in other genera of family Myrtaceae by Metcalfe and Chalk (1950); Schmid and Baas (1984) and Patel (1995). In *S. nervosum*, scalariform inter-vessel pits were seen in some parts of vessels which may be due to fusion of adjacent pits.

Fibres were thin-walled and non-septate in all species. Occasional septate fibres and vasicentric tracheids were observed in *S. nervosum* and *S. jambos*. Vasicentric tracheids play an essential role in xylem conduction efficiency and decrease the chances of embolism in vessels (Barotto et al., 2016). The presence of septate fibres in *S. jambos* and *S. nervosum* may be due to presence of less percentage of parenchyma in these species as septate fibres are liable for transportation and also storage of photo-assimilates in plants with less parenchyma (Evert, 2006).

The axial parenchyma was diffuse, diffuse in aggregate, vasicentric, aliform and confluent types. Hence, there was no variation in types of axial parenchyma. Vestured bordered pits were seen in *S. cumini*, *S. fruticosum*, *S. nervosum* and *S. praecox*. In the present study, disjunctive ray parenchyma cells were present in all species and corroborated the findings of Patel (1995).

Mineral inclusions are also important features for identification of wood. In the present study, prismatic shaped crystals were found in fibres and axial parenchyma of *S. nervosum* and even in ray and axial parenchyma of *S. fruticosum*. Silica bodies were observed in axial parenchyma of *S. jambos* in radial section. The present investigation is in agreement with the findings of van Vilet and Bass (1984) who reported crystals in genus *Lophomyrtus*.

Most of the anatomical characteristics existed significant variation within species which may be due to the collection of samples from unknown age of selected trees. On the contrary to it, Pande et al. (2005, 2007) reported non-significant variation in wood elements within species. The highly significant difference in anatomical parameters among species confirms the findings of other workers (Sharma et al., 2011a, 2011b; Singh et al., 2013) who reported the similar results in other hardwood species. Thus, the present study indicates that *Syzygium* species can be differentiated based on quantitative anatomical characteristics.

The present investigation reveals a close relationship among selected species. Though *S. jambos* was also in the same axis, but it forms a separate cluster. There was a close relationship between *S. fruticosum* - *S. nervosum* and *S. cumini* - *S. praecox*. The present study is in agreement with the findings of Biffin et al. (2006) who reported *S. cumini*, *S. jambos* and *S. nervosum* in the same group by using cpDNA sequence from matK and ndhF genes and rpl16 intron.

The wood density and moisture content of *Syzygium* species showed maximum density and minimum moisture content in *S. jambos* as compared to other species. Higher fibre percentage with thick-walled fibres in *S. jambos* may be the probable reason for its highest density and lowest moisture content.

The identification key for investigated species is given below:

1. Homocellular and heterocellular rays, vessels barrel to tube-shaped without spiral thickenings in tail 2
   1a. Homocellular and heterocellular rays, vessels barrel to tube-shaped without spiral thickenings in tail 3
2. Vessel diameter more than 100 µm, vasicentric tracheids and silica bodies absent 4
   2a. Vessel diameter was less than 100 µm, vasicentric tracheids and silica bodies present .... *S. jambos*.
3. Uniseriate, biseriate and multiseriate rays, diffuse, diffuse-in-aggregate and confluent parenchyma, vessel-ray pits horizontal to vertical --------------------------------- *S. cumini*.
   3a. Uniseriate, biseriate and multiseriate rays, diffuse, diffuse-in-aggregate and confluent parenchyma, vessel-ray pits simple and rounded .... *S.praecox*.
4. Multiseriate rays present, aliform, confluent parenchyma and crystals present in rays .... *S. fruticosum*.
   4a. Multiseriate rays present, vasicentric parenchyma and crystals present in fibres .... *S. nervosum*.

IV. CONCLUSION

The detailed anatomical characteristics of five *Syzygium* species of Manipur, India revealed that both qualitative features and quantitative anatomical characteristics could be used for identification. Diffuse porous and indistinct growth rings were present in all selected species except *Syzygium cumini* and *Syzygium fruticosum* (semi-ring porous and distinct). Vasicentric tracheids were present in *Syzygium jambos*, and septate fibres were observed in *Syzygium nervosum* and *Syzygium fruticosum*. Silica bodies were present in axial parenchyma of *Syzygium jambos* whereas crystals were observed in the ray of *Syzygium nervosum* and *Syzygium fruticosum*. *Syzygium jambos* had maximum fibre percentage, wood density and minimum moisture content. All the selected species showed significant variations in their quantitative anatomical and physical characteristics. Identification key was prepared for investigated species.

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THE DRYING PERFORMANCE AND POST-DRYING QUALITIES OF *Eucalyptus saligna* EXPOSED TO INTERMITTENT AND CONTINUOUS DRYING*

Karnita Yuniarti[1**], Barbara Ozarska[2**], Graham Brodie[2], Gerry Harris[2] and Gary Waugh[2]

[1]Center of Forest Products Research and Development Ministry of Environment and Forestry
Jl. Gunung Batu No. 5, West Java, Indonesia
[2]University of Melbourne, Parkville, Victoria 3010, Australia

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THE DRYING PERFORMANCE AND POST-DRYING QUALITIES OF *Eucalyptus saligna* EXPOSED TO INTERMITTENT AND CONTINUOUS DRYING. *Eucalyptus saligna* tends to develop defects during its drying process, thus limiting its use as construction or furniture material. Intermittent drying, which applies non-heating phases between heating phases, has the potential to overcome this issue. This study evaluated the effects of 3 intermittent and one continuous schedule on the species' drying performance and post-drying qualities. The results showed that the boards from all intermittent schedules exhibit significantly slower drying rates (from -9.4×10^{-3} %/hour to -1.57×10^{-2} %/hour) than those from the continuous schedule (from -5.12×10^{-2} /hour to -1.03×10^{-2} %/hour). All intermittent schedules tended to decrease the collapse depth in *E. saligna* boards (the average value range of the three schedules was 1.162-2.032 mm) than the continuous schedule did (the average value was 5.12 mm). Nevertheless, applying higher temperature than that used in the continuous schedule, during the heating phase of the intermittent schedule, potentially increased the moisture gradient, residual drying stress, end check length, internal check percentage, and spring depth.

Keywords: *Eucalyptus saligna*, drying performance, drying defects, intermittent drying, a continuous drying

PERFORMA DAN KUALITAS PENGERINGAN Eucalyptus saligna *PADA PENGERINGAN INTERMITEN DAN KONTINYU.* Eucalyptus saligna *memiliki kecenderungan untuk mengalami cacat pengeringan, sehingga membatasi penggunaannya sebagai bahan konstruksi atau furnitur. Pengeringan intermiten, yang menerapkan fase pendinginan diantara fase pemanasan, berpotensi mengatasi masalah ini. Studi ini mengevaluasi pengaruh 3 skedul intermiten dan 1 skedul pengeringan kontinyu terhadap performa dan kualitas pengeringan jenis ini. Hasil studi menunjukkan papan-papan yang dikeringkan secara intermiten memiliki laju pengeringan lebih lambat (dari* $-9{,}4 \times 10^{-3}$*%/jam ke* $-1{,}57 \times 10^{-2}$*%/jam) dari yang dikeringkan secara kontinyu (dari* $-5{,}12 \times 10^{-2}$*%/jam ke* $-1{,}03 \times 10^{-2}$*%/jam). Kedalaman kolaps yang terbentuk pada papan-papan yang dikeringkan secara intermiten juga lebih rendah (1,162-2,032 mm) dari yang dikeringkan secara kontinyu (5,12 mm). Walaupun demikian, penerapan suhu pengeringan yang lebih tinggi pada teknik intermiten dibandingkan dengan yang diterapkan pada teknik kontinyu berpotensi meningkatkan gradien kadar air, stress akhir pengeringan, panjang pecah ujung, persentase pecah dalam dan kedalaman pelengkungan kayu arah lebar sepanjang kayu.*

Kata kunci: Eucalyptus saligna*, performa pengeringan, cacat pengeringan, pengeringan intermiten, pengeringan kontinyu*

* This study has been presented in the General Assembly and the 3rd International Symposium of JSPS Alumni Association of Indonesia (ISJAAI-3) "The Role of JAAI to Promote Food, Water, Energy, Human, and Environmental Security", held on 31 October 2019 at Hotel Salak The Heritage, Bogor, West Java, Indonesia.

**Corresponding author: karnita_yuniarti@yahoo.com, bo@unimelb.edu.au

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I. INTRODUCTION

Eucalyptus saligna or Sydney blue gum is a species that belongs to the Eucalyptus genus, a native to Australia, which is included in the Myrtaceae family (Elaieb et al., 2019). The species has now been grown outside Australia, including in China, Tunisia, Brazil, and Costa Rica (Arias-Aguilar et al., 2018; Beltrame et al., 2013; de Castro et al., 2015; Elaieb et al., 2019; Yang & Liu, 2018). It is mainly cultivated for meeting the consumer demand on timber, pulp and essential oils which contain medicinal compounds (Elaieb et al., 2019; Luís, Nisgoski, & Klitzke, 2018; Yang & Liu, 2018).

A common issue often encountered during the utilization of any Eucalyptus species, including *E. saligna*, is the difficulties in their drying process. Due to its low permeability, slow drying, the development of high moisture gradients and collapse often observed in the majority of Eucalyptus species (Passarini & Hernandez, 2016; Yuniarti, Ozarska, Brodie, Harris, & Waugh, 2015). *E. saligna* even develops collapse at low temperature (25°C) and posseses a lower collapse threshold temperature than *E. regnans* does (Yuniarti et al., 2015). Because it tends to develop drying defects, such as internal checking, collapse and shrinkage, post-drying recovery is recorded still low (Elaieb et al., 2019). This phenomenon could further limit its use as construction or furniture materials.

A review composed by Yang and Liu (2018) has proposed intermittent drying as an alternative technique can be opted to improve the drying quality of several Eucalyptus species. The method was firstly applied in enhancing the quality of several food crops, i.e. paddy, onion, soybean, etc. (Allaf et al., 2014; Golmohammadi, Foroughi-dahr, Rajabi-hamaneh, Shojamoradi, & Hashemi, 2016; Park, Han, Kang, & Yoo, 2017; Takougnadi, Boroze, & Azouma, 2018). It works by introducing regular interruption during the drying process (Allaf et al., 2014; Yang & Liu, 2018). Due to this periodic non-heating condition, more uniform distribution of moisture content and stress relaxation are expected to occur in the internal part of the wood (Yang & Liu, 2018).

Up to now, studies on the application for intermittent drying for wood, in particular, to minimize the tendency possessed by *E. saligna* to develop drying defects have not received any attention. Therefore, this specific study aimed to examine the efficacy of various intermittent conditions in reducing the development of drying defects and also compare its effectiveness with the continuous schedules on both improving the drying performance and post-drying quality of *E. saligna*.

II. MATERIAL AND METHOD

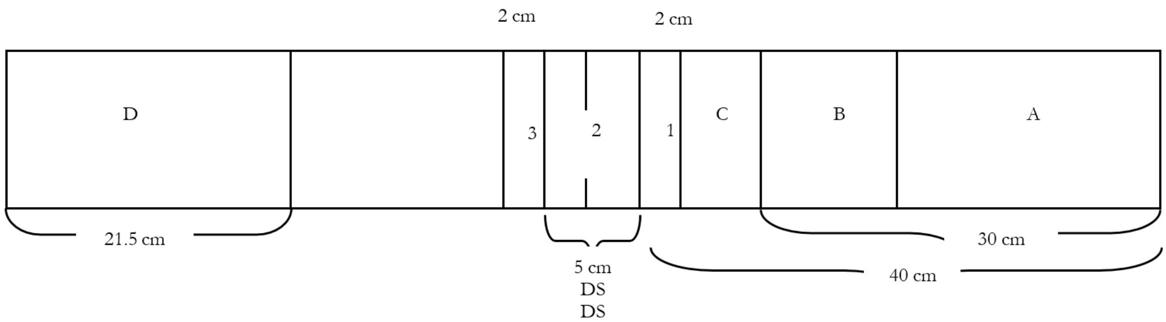
A. Study Site and Materials

The study was conducted in the Burnley campus, the University of Melbourne, from January 2013 to September 2014. The primary material used for this experiment was *E. saligna* boards with original length was 860 mm. Two biscuits, sizing 20 mm width, were taken at a distance of 50 mm from both ends of each board. These biscuits were used to determine the initial moisture content of each board. All boards were end sealed with silicone sealant and aluminium foils before the drying process. Each board was also marked following the pattern shown in Figure 1 below. The design was later used as guidance for cutting process of samples for measuring residual drying stress, observing internal checks and collapse. The experiment was carried out using three drying kilns in the carpentry workshop, Burnley campus, the University of Melbourne. Other equipment and tools used for this experiment were bandsaws, rip-saw, oven, scale, digital calliper, and a moisture meter.

B. Methods

The study applied three intermittent schedules and one continuous schedule as follow:

(i) Intermittent 1: heating phase for 13 hours at 38°C and relative humidity of 60%, followed by non-heating at ambient condition for 11 hours (condensed as 38°C/60%, 13H/11NH);



Remarks: 1 - Final moisture content biscuit; 2 - Drying stress sample (DS); 3 - Prong test sample
B, C, D, DS - Internal check observation; A, D, DS – Collapse observation

Figure 1. Observation and cutting pattern for each dried board

(ii) Intermittent 2: heating period heating phase for 11 hours at 42°C and relative humidity of 60%, followed by non-heating at ambient condition for 13 hours (condensed as 42°C/60%, 11H/13NH);
(iii) Intermittent 3: heating phase for 9 hours at 45°C and relative humidity of 60%, followed by non-heating at ambient condition for 15 hours (condensed as 45°C/60%, 9H/15NH).
(iv) Continuous drying at 40°C and relative humidity of 60% (condensed as 40°C/60%)

For all intermittent schedules, the heating phase was carried out during the day, and the non-heating phase was carried out at night. The fan speed was 300 rpm (or equal to 10 GHz) for both phases. For continuous schedule, the air velocity applied was 12 Ghz (fan speed of 350 rpm). Each schedule was carried out in different kilns.

Approximately three runs were applied for each schedule, except for intermittent one which only applied two runs. The number of boards used was 12 for each run, except for the 3rd run of the continuous schedule (10 boards). The boards were stacked using the assistance of 20-mm thick wooden stickers. Baffles were placed on the top and in front of the stack to avoid excessive airflow around those sections. The boards were weighed daily after each heating and non-heating phases, except in the weekend. After all, boards reached the final moisture content range of 10–15%; the drying was stopped. A 20-mm thick biscuit was cut from the middle of each board and further used to correct the moisture content values of the related board.

C. Analysis

The parameters observed from each drying schedule are:

(i) Drying performance parameters which were drying rate and time. The drying rate was determined by firstly transforming the moisture reduction data for each board into their natural logarithm values. Each data set from each board was then plotted in a graph with x-axis represented time (hour), and y-axis represented moisture content (%). A linear equation was then applied to each figure. The drying rate for each board was the slope of the linear equation. Drying time was measured from the starting time of the drying process to the time when the average final moisture content of all the boards was approximately 10–15%.
(ii) Post drying quality parameters followed those described in Australian standard-AS/NZS 4787:2001 to assess the furniture and joinery grade products which were moisture gradient, residual drying stress, checking (surface check, end check, and internal check), distortion (bow, spring, twist, and cupping) and collapse. Except for distortion,

the assessment and classification for the other parameters followed the procedures described in AS/NZS 4787:2001. The assessment and classification for distortion followed the methods described in AS/NZS 2082: 2007.

One-way analysis of variance (ANOVA) was carried out to examine the significant effect of different intermittent and continuous drying schedules on the drying rate, moisture gradient and residual drying stress separately. Before that, a normality test was executed, i.e. Shapiro Wilk. If the normality test result meets the requirement, indicated by a probability value of more than 0.001, then the general parametric ANOVA test was executed. Otherwise, data transformation might be required, and a non-parametric ANOVA test was applied, i.e. Kruskal-Wallis. Following test, such as Tukey (for parametric procedure) and Mann-Whitney U (for non-parametric method), were used if the previous ANOVA tests showed significant results. The null hypothesis for each parameter was all drying schedules had no significant effect on the drying rate, moisture gradient and residual drying stress. Other post-drying quality parameters were tabulated, presented into graphs and analysed descriptively.

III. RESULT AND DISCUSSION

A. Drying Rate and Time

Table 1 shows the drying rate from all intermittent schedules ranged from -9.4x10^{-3} %/hour to -1.57 x10^{-2} %/hour, slower than that of the continuous drying which ranged from -5.12 x10^{-2} %/hour to -1.03 x10^{-2} %/hour. All intermittent schedules required a longer time (696–4403 hours) than the continuous drying

Table 1.Average drying rate (/hour) and time (hour) of intermittent and continuous drying of *E. saligna*

Schedule	Rep **	Moisture content range (%)		Drying rate range (%hour) *		Drying time range (average, hour)	
		Green	Final	Min	Max	Min	Max
Intermittent 13-hour heating at 38°C, 60%RH and 11-hour non-heating at ambient condition	1	79.87-106.79	11.52 -12.39	-6.6 x10^{-3}	-3.4 x10^{-3}	3273	3753
	2	86.01-137.24	11.88-12.65	- 6.6 x10^{-3}	-3.3 x10^{-3}	3683	3951
Intermittent 11-hour heating at 42°C, 60%RH and 13-hour non-heating at ambient condition	1	80.34-111.62	11.20 -13.67	-2.7 x10^{-2}	-2.04 x10^{-2}	971	1248
	2	70.44-88.23	11.55 - 11.97	-2.26 x10^{-2}	-1.58 x10^{-2}	1176	1632
	3	79.72 - 148.99	11.56-13.01	-2.4 x10^{-3}	- 2.4 x10^{-3}	4163	4403
Intermittent 9-hour heating at 45°C, 60%RH and 15-hour non-heating at ambient condition	1	80.55-126.13	11.79-14.99	-2.48 x10^{-2}	-1.57 x10^{-2}	1281	1599
	2	71.62-84.42	11.64 - 11.99	-4.10 x10^{-2}	-1.69 x10^{-2}	696	1488
	3	83.46-159.03	10.68-11.87	- 9.4 x10^{-3}	-4.5 x10^{-3}	2823	
Continuous process at 40°C, 60%RH	1	80.59-113.87	11.70-11.99	-3.39x10^{-2}	-2.3 x10^{-2}	780	1092
	2	85.81-120.68	11.48-11.99	-5.12x10^{-2}	-2.11x10^{-2}	588	1092
	3	76.27-132.39	11.61-12.29	-3.90x10^{-2}	-1.03 x10^{-2}	876	1992

Remarks : * indicates declining trend; **each replication consisted of 12 samples

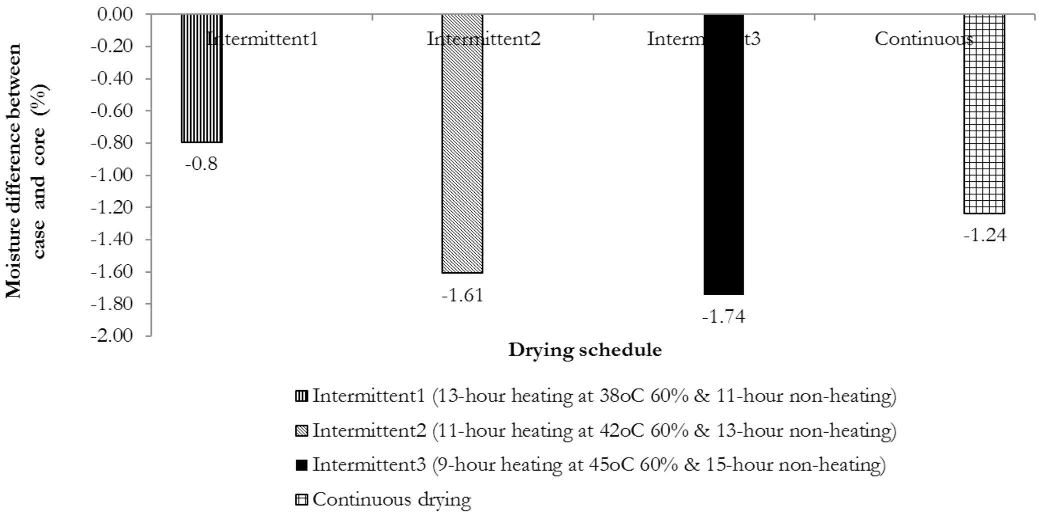


Figure 2. Average moisture gradient (between the case and core) in *E. saligna* exposed to the intermittent and continuous drying schedules

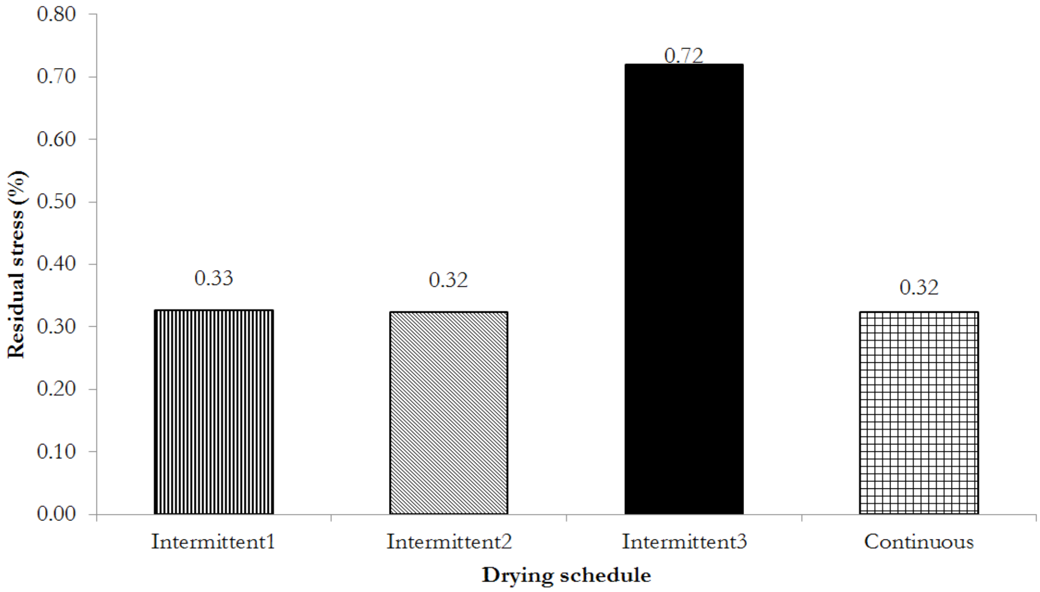


Figure 3. Average residual stress (%) in *E. saligna* exposed to the intermittent and continuous drying schedules

did (588-1992 hours) to dry *E. saligna* to reach moisture content 12% ±3.

Further ANOVA showed that the drying schedules significantly affected the drying rate. A subsequent test showed that the drying rate between the intermittent schedules and continuous schedules was significantly different, but not between the intermittent schedules 2 and 3 (Appendix 1). The significant difference between intermittent and continuous schedules was due to the uninterrupted heating condition in the continuous drying, which caused the wood to dry faster than those from the intermittent schedule.

B. Moisture Gradient

Figure 1 shows the boards from the intermittent schedule 3 had the highest

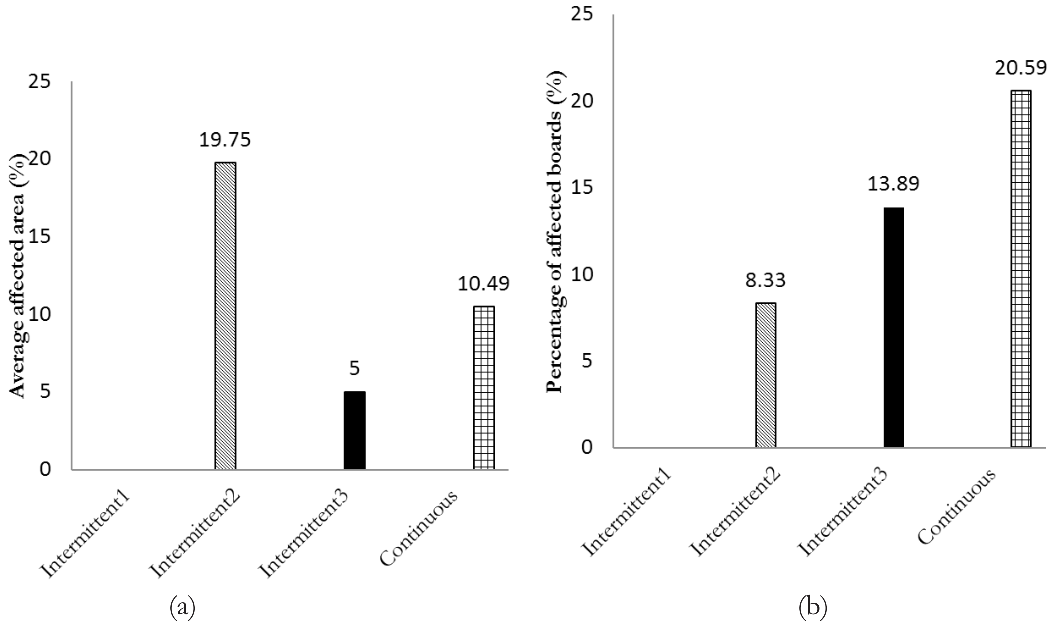


Figure 4. The affected area by surface check (a) and the percentage of *E. saligna* boards with this defect (b) from the intermittent and continuous drying schedules

(-1.74%), and schedule 1 had the lowest value (-0.80%) of moisture gradient. The use of higher temperature during the practice of intermittent schedule 3 than that used for the intermittent schedule 1 possibly contributed to this result. Further ANOVA confirmed that different drying schedules significantly affected the moisture gradient values (Appendix 2).

C. Residual Drying Stress

Figure 3 shows the boards subjected to the intermittent schedule 3 developed the highest average residual drying stress (0.72%). The result was unexpected and assumed to be due to the high temperature used for this schedule. On the other hand, the lowest residual drying stress, 0.32%, was found for the boards exposed to the intermittent schedule 2. The boards from the continuous drying schedule also generated the same residual drying stress degree. This result implies that drying *E. saligna* with either continuous or intermittent schedule 2 will produce the same degree of residual drying stress. Further ANOVA confirmed that the degree of residual stress was significantly affected by the drying schedules applied (Appendix 3).

D. Checking

Surface check

Figure 4 shows the average affected area due to surface checks and the percentage of boards affected by this defect from the intermittent and continuous drying schedules. The surface checks were not found in the boards from the intermittent schedule 1. The highest affected area due to the surface check was observed in the boards from the intermittent schedule 2 (19.75%).

Nevertheless, the highest percentage of boards affected by the surface check was from the continuous drying schedule (approximately 20.59% of the boards observed). This result was possibly due to the uninterrupted heating condition during the continuous drying. This continuous heating condition did not provide sufficient momentum for moisture equalization between the surface and the interior of the wood. The surface kept drying whilst the interior section of the wood was still wet, resulting in more surface checks.

The intermittent schedule 3, on the other hand, produced the lowest percentage of boards affected by surface check (13.89%)

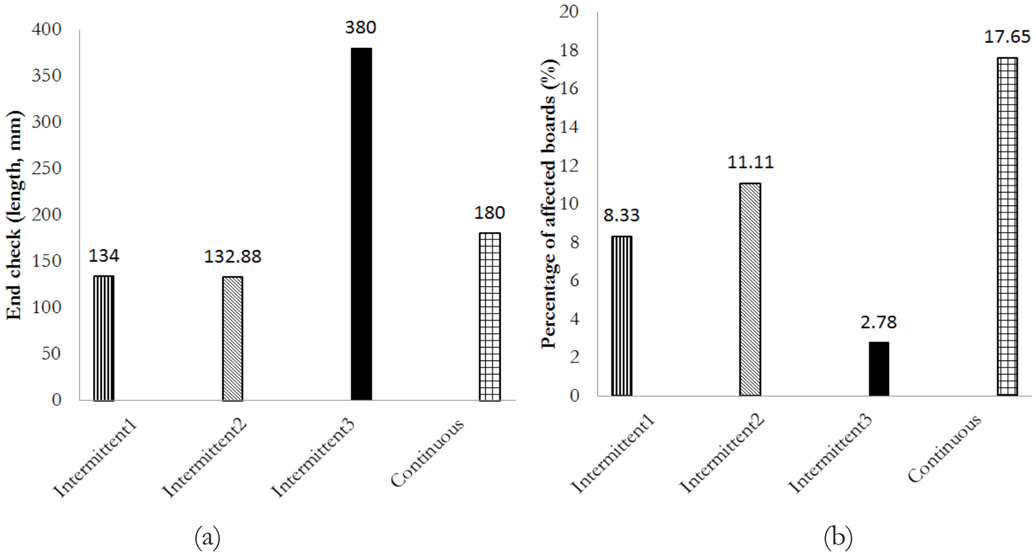


Figure 5. End check length (a) and the percentage of *E. saligna* boards with end checks (b) from the intermittent and continuous drying schedules

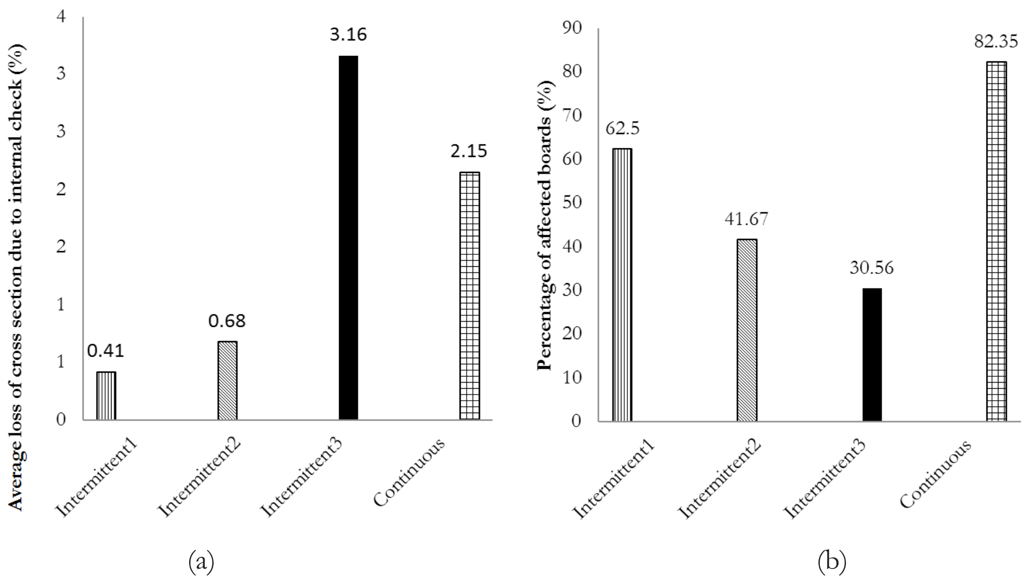


Figure 6. Internal check degree (% affected area) (a) and the percentage of *E. saligna* boards with this defect (b) from the intermittent and continuous drying schedules

and the lowest affected area (5%). This result was possibly due to the long non-heating period during the intermittent schedule 3, which provide recovery time for the boards to relieve surface checks. This result indicates that particular intermittent drying schedule is potential to reduce the tendency of *E. saligna* to develop surface checks during its drying process.

End check

Figure 5 shows the highest average length of end checks in the boards was from the intermittent schedule 3 (380 mm). The average lengths of end checks in the boards from the other intermittent schedules were lower than that from the continuous drying schedule. This result indicates that several intermittent drying schedules have the potential to reduce the tendency of *E. saligna* to develop end checks during its drying process.

Nevertheless, end checks only affected 2.78% of the boards used in the trial of intermittent schedule 3. The highest percentage of boards affected by end checks was from the continuous drying schedule. Approximately 17.65% of the boards subjected to the continuous trial were found with end checks.

Internal check

The study found that that the longitudinal direction of the internal checks commonly laid along the wood ray or perpendicular to the growth ring. Figure 6 further shows the percentage of boards affected by internal checks in the boards from all intermittent drying schedules was lower than that from the continuous drying schedule (82.35%). This result indicates that the intermittent drying has the potential to reduce the tendency of *E. saligna* to develop internal checks during its drying process. Nevertheless, the highest average cross-section loss due to the presence of internal checks was found for the boards from the intermittent schedule 3 (3.16%). Phonetip (2018) recommended using an imaging software to quantify the cross-section loss instead of the calliper method introduced in Australian New Zealand Standard AS/NZS 4787:2001. He argued that the imaging software technique captured the original shape of the internal check better than the calliper method. His study found that using imaging software technique resulted in a smaller figure than the calliper method did. However, it still has less effect on the grading classification of the wood according to the refereed standard.

Furthermore, review of Figures 4-6 shows that the internal checks were the dominant type of defect found for *E. saligna* regardless of the drying schedule used. The number of boards affected by other checks from all schedules was lower than those affected by internal checks. Of all the three check types, the internal check is possibly the most significant defect due to its concealed nature. The presence of internal checks is often only revealed after the drying process ends or during further manufacturing processing. Due to its presence, the industry is possibly not able to utilize the affected boards for high-quality products.

E. Distortion

Figure 7 shows the average value of cupping, bow, spring and twist developed in *E. saligna* boards from the intermittent and continuous drying schedules. Boards from the continuous

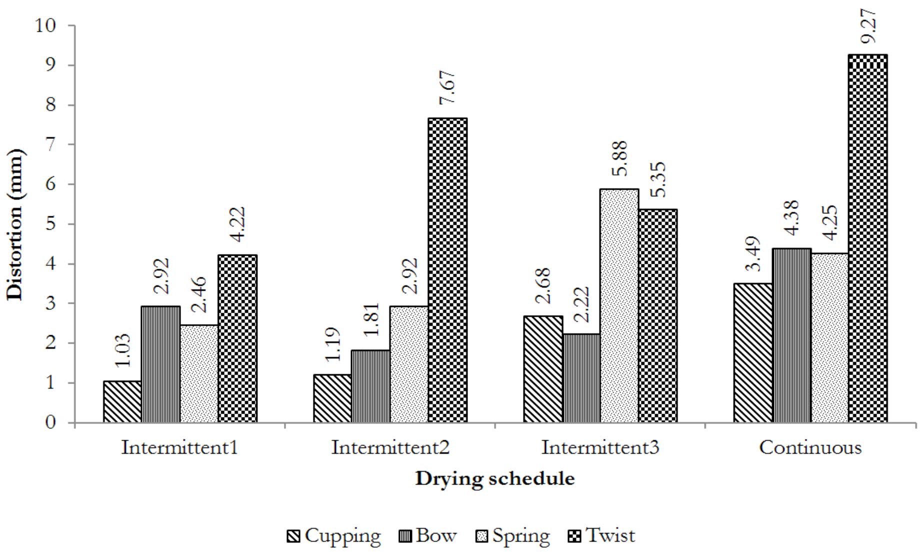


Figure 7. Cupping, bow, spring and twist in *E. saligna* boards from the intermittent and continuous drying schedules

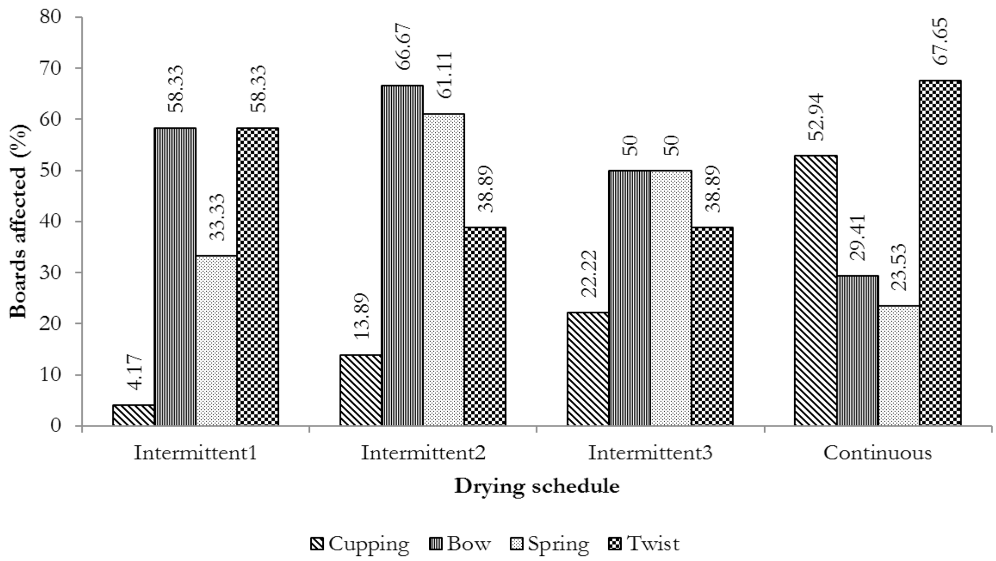


Figure 8. Percentage of boards affected by each distortion from the intermittent and continuous drying schedules

drying schedule had a higher average depth of twist (9.27 mm), bow (4.38 mm) and cupping (3.49 mm) than those from the intermittent drying schedules (Figure 7). This result was possibly due to interrupted heating condition in the intermittent drying schedule, which allowed moisture redistribution in the wood. The highest spring, on the other hand, was observed in the boards from the intermittent schedule 3 (5.88 mm) (Figure 7). The lowest spring depth was found for the boards from intermittent schedule1 (2.46 mm) (Figure 7).

Figure 8 shows the percentage of boards affected by each distortion type from intermittent and continuous drying schedules. The twist was not only the distortion type with the highest degree among other distortion for the boards from the continuous drying schedule (9.27 mm) (Figure 7) but also the most frequently found. The number of boards from the continuous schedule with a twist (67.65%) was the highest among other schedules (Figure 8). The continuous schedule also caused the highest number of boards with cupping, among other schedules (53%).

For intermittent schedule 1, twist and bow were the two most dominant distortion types and affected 58.83% of the boards from this intermittent schedule (Figure 8). Nevertheless, the twist was the distortion type with the highest degree among other defects for boards from the intermittent schedule 1 (4.22 mm) (Figure 7).

For the boards from the intermittent schedules 2, the bow was also the most frequent distortion found and affected 66.67% of the boards used for this schedule (Figure 8). The percentage of boards with the bow from this schedule was the highest among other schedules. As well, the number of boards from this schedule with spring (61.11%) was also the highest among other schedules (Figure 8). Nevertheless, the twist was still the type of distortion with the highest degree among other defects for the boards from the intermittent schedule 2 (7.67 mm) (Figure 7).

For the boards from the intermittent schedules 3, bow and spring were the two dominant distortion types found and affected 50% of the boards used for this schedule (Figure 8). Spring, on the other hand, was the distortion type with the highest degree among other defects for the boards from the intermittent schedule 3 (5.88 mm) (Figure 7).

The result obtained has shown that all distortion types developed to different degrees

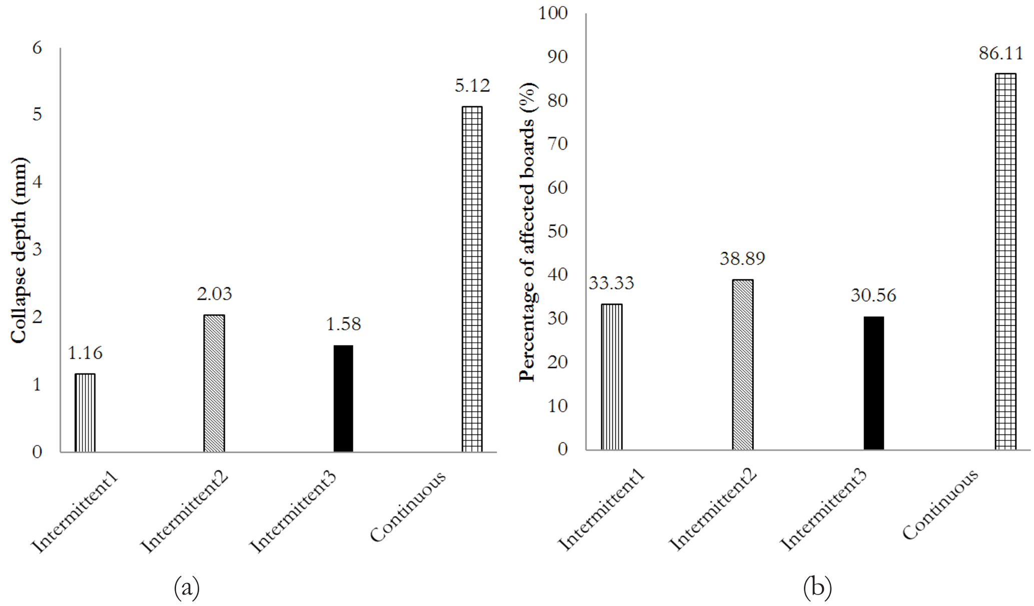


Figure 9. Average collapse depth in *E. saligna* boards and percentage of affected boards from the intermittent and continuous drying schedules

in *E. saligna* boards from the intermittent and continuous drying schedules. It is possible that when a particular distortion develops to a particular degree within board, the other distortion defects do not occur or develop at a different degree. Furthermore, the dominant distortion type developed can also indicate the possible wood reaction to the stress formed during the drying process.

F. Collapse

Figure 9 shows the average collapse depth in *E. saligna* boards and the percentage of affected boards from the intermittent and continuous drying schedules. The boards from all intermittent schedules developed a smaller degree of collapse (1.16-2.03 mm in depth) than those from the continuous schedule (5.12 mm). As well, the percentage of affected boards from the intermittent schedules (30.56-38.89%) was smaller than that from the continuous schedule (86.11%).

The low level of collapse in intermittently-dried boards, in comparison to those observed in the continuously-dried boards, is assumed to be due to the inclusion on non-heating phase, which allows redistribution of moisture content. This phenomenon could assist in improving the permeability of wood, thus inducing internal stress relaxation. According to Elaieb et al. (2019), increased permeability should allow the wood to minimize its tendency to develop collapse. Another intermittent drying experiment with *Eucalyptus delegatensis* as the object revealed that increasing relative humidity up to 80-90% during the non-heating phase was potential to reduce both the depth and percentage of boards affected by collapse (Phonetip, 2018).

On the other side, the high degree of collapse in the continuously-dried boards, in the context of the collapse depth and the percentage of affected boards, could be driven by non-stop heating from the beginning of the process. According to Couceiro, Vikberg, Hansson, and Morén (2016), rapid warming up phase during a drying process will lead to collapse and crack in the wood in the early stages. Yuniarti et al. (2015) observed that continuous heating, even at a temperature as low as 20–25°C, still triggered some collapse to occur on *E. saligna* which was indicated by corrugated surfaces and internal checks.

IV. CONCLUSION

The study has shown that all intermittent schedules needed longer time (approximately 696–4403 hours) than the continuous drying did (approximately 588-1992 hours) to dry *E. saligna* to reach moisture content 12% + 3. The drying rate of all intermittent schedules applied (from $-9.4x10^{-3}$ %/hour to $-1.57\ x10^{-2}$ %/hour) was slower than that of the continuous drying (from $-5.12\ x10^{-2}$ %/hour to $-1.03\ x10^{-2}$ %/hour.). Further analysis of variance test showed that the drying schedules significantly affected the drying rate. The intermittently-dried boards generally possessed a lower degree of cupping, bow, twist, and collapse; and smaller percentage of boards affected by all checks types, cupping, twist and collapse than the continuously-dried boards did. Nevertheless, applying a higher heating-phase temperature in intermittent drying schedule (intermittent schedule 3) than that applied in the continuous schedule potentially increased the tendency of *E. saligna* to develop the steepest internal moisture gradient and average residual drying stress. It also possibly raised the percentage of cross-section loss due to the internal check presence, the length of the end check, and the depth of spring.

Further observation shows that internal check was the most frequent check developed in *E. saligna* boards from both intermittent and continuous drying schedules. Twist was the most frequent distortion occurred in the boards from the continuous schedule. Boards from intermittent schedule 1 also developed mostly twist and bow. The bow was also the dominant distortion in the boards from intermittent schedules 2 and 3. Besides, spring was also found to be the other dominant distortion for the boards from intermittent schedule 3. All intermittent schedules trialled for this experiment are suitable for *E. saligna*. However, if a moderate drying period and defects are the considerations, intermittent schedule 2 or 3 could be opted for the time being. To obtain faster drying period with minimum or no defects will require further intensive experiments.

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APPENDICES

Appendix 1. One-way ANOVA to assess the significant effect of applied drying schedule on drying rate

A. Shapiro-Wilk test for Normality*
Data variate: Slope
Test statistic W: 0.9286
Probability: <0.001
*Remarks : *All transformation did not work*

B. Kruskal-Wallis one-way analysis of variance
Variate: Slope
Group factor: Schedule
Value of H = 55.11
Adjusted for ties = 55.12

Sample	Size	Mean rank
Group Continuous	34	32.91
Group Intermittent1	24	106.52
Group Intermittent2	36	71.79
Group Intermittent3	36	62.64

Degrees of freedom = 3 Chi-square probability < 0.001

C. Subsequent test: Mann-Whitney U (Wilcoxon rank-sum) test
(i) Variates: Intermittent1, Intermittent2.
Value of U: 263.5 (first sample has higher rank sum).
Exact probability (adjusted for ties): 0.010 (under null hypothesis that Intermittent1 is equal to Intermittent2).
Sample sizes: 24, 36.

(ii) Variates: Intermittent1, Intermittent3.
Value of U: 24.0 (first sample has higher rank sum).
Exact probability < 0.001(under null hypothesis that Intermittent1 is equal to Intermittent3).
Sample sizes: 24, 36.

(iii) Variates: Intermittent1, Continuous.
Value of U: 0.0 (first sample has higher rank sum).
Exact probability < 0.001 (under null hypothesis that Intermittent1 is equal to Continuous).
Sample sizes: 24, 34.

(iv) Variates: Intermittent2, Continuous
Value of U: 255.0 (first sample has higher rank sum).
Exact probability (adjusted for ties) < 0.001 (under null hypothesis that Intermittent2 is equal to Continuous).
Sample sizes: 36, 34.

(v) Variates: Intermittent3, Continuous.
Value of U: 269.0 (first sample has higher rank sum).
Exact probability (adjusted for ties) < 0.001(under null hypothesis that Intermittent3 is equal to Continuous).
Sample sizes: 36, 34.

(vi) Variates: Intermittent3, Intermittent2.
Value of U: 610.0 (second sample has higher rank sum).
Exact probability (adjusted for ties): 0.673(under null hypothesis that Intermittent3 is equal to Intermittent2).
Sample sizes: 36, 36.

Appendix 2. Statistical analysis for the difference in moisture gradient values between three intermittent and one continuous schedules

A Normality Test: Shapiro-Wilk test*
Data variate: Difference
Test statistic W: 0.7762
Probability: <0.001
*Remarks: *All transformation did not work.*

B. Main test: Kruskal-Wallis one-way analysis of variance*
Variate: Gradient
Group factor: Schedule
Value of H = 20.78 Adjusted for ties = 20.78

Sample**	Size	Mean rank
Group Int1	24	93.27
Group Int2	36	59.04
Group Int3	36	49.76
Group Cont	33	67.56

Degrees of freedom = 3 Chi-square probability < 0.001

Remarks: * This non-parametric ANOVA was opted after normality test showed the data was not normally distributed and no transformation attempts were successful to improve it.

C. Subsequent test : Mann-Whitney U (Wilcoxon rank-sum) test
(i) Variates: Intermittent1, Intermittent 2.
Value of U: 234.5 (first sample has higher rank sum).
Exact probability (adjusted for ties): 0.002 (under null hypothesis that Sched1 is equal to Sched2). Sample sizes: 24, 36.

(ii) Variates: Intermittent 1, Intermittent 3.
Value of U: 150.0 (first sample has higher rank sum).
Exact probability (adjusted for ties) < 0.001 (under null hypothesis that Sched1 is equal to Sched3). Sample sizes: 24, 36.

(iii) Variates: Intermittent 1, Continuous.
Value of U: 197.0 (first sample has higher rank sum).
Exact probability (adjusted for ties): 0.002 (under null hypothesis that Sched1 is equal to Sched4). Sample sizes: 24, 33.

(iv) Variates: Intermittent 2, Intermittent 3.
Value of U: 577.0 (first sample has higher rank sum).
Exact probability (adjusted for ties): 0.428 (under null hypothesis that Sched2 is equal to Sched3). Sample sizes: 36, 36.

(v) Variates: Intermittent 2, Continuous.
Value of U: 473.0 (second sample has higher rank sum).
Exact probability (adjusted for ties): 0.208 (under null hypothesis that Sched2 is equal to Continuous). Sample sizes: 36, 33.

(vi) Variates: Intermittent 3, Continuous.
Value of U: 365.5 (second sample has higher rank sum).
Exact probability (adjusted for ties): 0.009 (under null hypothesis that Sched3 is equal to Continuous). Sample sizes: 36, 33.

Appendix 3. Statistical analysis for differences in drying residual stress (standard-slicing test) between continuous and three intermittent schedules

A Normality test : Shapiro-Wilk test*
Data variate: Stress
Test statistic W: 0.8643
Probability: <0.001

Transformation
Data variate: StressSQRT
Test statistic W: 0.9839
Probability: 0.161

B. Main test : 1-Way analysis of variance of an unbalanced design
Variate: Stress SQRT (the stress values were transformed into square root forms to obtain normal distribution)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Schedule	3	2.16014	0.72005	14.59	<.001
Residual	117	5.77500	0.04936		
Total	120	7.93514			

C. Subsequent test: Tukey test 95% confidence intervals

Comparison*	Difference	Lower 95%	Upper 95%	Significant
4 vs 2	-0.0010	-0.1464	0.1444	no
4 vs 1	-0.0198	-0.1815	0.1418	no
4 vs 3	-0.3025	-0.4489	-0.1561	yes
2 vs 1	-0.0188	-0.1742	0.1366	no
2 vs 3	-0.3015	-0.4409	-0.1620	yes
1 vs 3	-0.2826	-0.4390	-0.1263	yes

Remarks:
* *Group 1= Intermittent at 38oC 60% RH, 13-hour heating, 11-hour non-heating*
Group 2 = Intermittent at 42 oC 60% RH, 11-hour heating, 13-hour non-heating
Group 3 = Intermittent at 45 oC 60% RH, 9-hour heating, 15-hour non-heating
Group 4 = Continuous at 40 oC 60% RH

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BENDING STRENGTH OF LIGNOCELLULOSIC MATERIALS IN SOFTENING CONDITION*

Wahyu Dwianto[1**], Ratih Damayanti[2], Teguh Darmawan[1], Prabu Satria Sejati[1], Fazhar Akbar[1], Danang Sudarwoko Adi[1], Adik Bahanawan[1], Yusup Amin[1], and Dimas Triwibowo[1]

[1]Research Center for Biomaterials, Indonesian Institute of Sciences, Jl. Raya Bogor Km. 46, Bogor 16911, West Java, Indonesia
[2]Forest Product Research and Development Center, Ministry of Environment and Forestry, Jl. Gunung Batu No.5 Bogor 16610, West Java, Indonesia

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BENDING STRENGTH OF LIGNOCELLULOSIC MATERIALS IN SOFTENING CONDITION. Manually rattan and bamboo are more easily bent than wood. A further question, whether these are due to the softening behaviour of chemical components or their anatomical structures. This research is aiming to understand the softening behaviour and viscoelastic property of wood, rattan and bamboo as lignocellulosic materials. Nine years-old fast-growing teak wood (*Tectona grandis* L.f.), rattan (*Calamus* sp.), and three-years-old andong bamboo (*Gigantochloa pseudoarundinaceae* (Steud.) Widjaja) were used for the experiments. Wood and rattan samples were taken from the bottom, middle and upper parts. Bamboo samples were cut from the 1st to 20th internodes. Static bending tests were carried out in fresh (green) as control samples, air-dried, and softened by microwave heating (MW) for 1 minute to determine the modulus of rupture (MOR) and modulus of elasticity (MOE). The results showed that the MOR and MOE values of wood, rattan, and bamboo increased from fresh to air-dried condition, and decreased by MW. When compared at the same density, a drastic increase was observed for the normalized MOR value in air-dried rattan, i.e. 2.5 fold. However, the decreasing of all the normalized MOR values were almost the same, i.e. 0.5 fold when MW softened them. The improvement also appeared for the normalized MOE value in air-dried rattan, i.e. 3 fold and decreased to almost zero by MW. These results indicated that rattan was more easily bent, followed by bamboo and then wood. Hydrothermal properties of chemical components significantly affected the changes of strength (MOR) and elastic properties (MOE). However, the differences in bending strength of wood, rattan, and bamboo were more likely due to differences in their anatomical structures.

Keywords: Bending strength, lignocellulosic materials, softening condition, anatomical structures

*KEKUATAN LENTUR DARI BAHAN BERLIGNOSELULOSA PADA KONDISI PELUNAKAN. Rotan dan bambu lebih mudah dilengkungkan daripada kayu secara manual. Pertanyaan selanjutnya, apakah hal ini disebabkan oleh perilaku pelunakan komponen kimia atau struktur anatominya. Oleh karena itu, penelitian ini bertujuan untuk memahami perilaku pelunakan dan sifat viskoelastik kayu, rotan, dan bambu yang merupakan bahan berlignoselulosa. Material yang digunakan dalam percobaan adalah sampel kayu jati (*Tectona grandis* *L.f.) cepat tumbuh berumur 9 tahun, rotan (*Calamus* *sp.), dan bambu andong berumur 3 tahun (*Gigantochloa pseudoarundinaceae* *(Steud.) Widjaja). Sampel diambil dari bagian bawah, tengah dan atas untuk kayu dan rotan, sedangkan untuk bambu dipotong dari ruas ke-1 sampai ke-20. Pengujian lentur statis dilakukan pada kondisi segar sebagai kontrol, kering udara, dan dilunakkan dengan pemanasan gelombang mikro (MW) selama satu menit untuk menentukan modulus patah (MOR) dan modulus elastisitas (MOE). Hasil penelitian menunjukkan bahwa nilai MOR dan MOE kayu, rotan, dan bambu meningkat dari kondisi segar ke kering udara, dan menurun dengan MW. Jika dibandingkan dengan kerapatan yang sama, terjadi peningkatan drastis dari nilai normalisasi MOR rotan pada kondisi kering udara, yaitu 2,5 kali lipat. Namun, penurunan nilai normalisasi MOR seluruhnya hampir sama, yaitu 0,5 kali lipat ketika dilunakkan dengan MW. Peningkatan luar biasa juga terjadi pada nilai normalisasi MOE rotan pada kondisi kering udara, yaitu 3 kali lipat dan menurun hampir nol dengan MW. Hasil ini menunjukkan bahwa rotan lebih mudah dilengkungkan, diikuti oleh bambu, kemudian kayu.*

[*]This study has been presented in the General Assembly and the 3rd International Symposium of JSPS Alumni Association of Indonesia (ISJAAI-3) "The Role of JAAI to Promote Food, Water, Energy, Human, and Environmental Security", held on 31 October 2019 at Hotel Salak The Heritage, Bogor, West Java, Indonesia.

[**]Corresponding author: wahyudwianto@yahoo.com

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Sifat hidrotermal komponen kimia secara signifikan mempengaruhi perubahan kekuatan (MOR) dan sifat elastis (MOE). Namun, perbedaan dari kekuatan lentur kayu, rotan, dan bambu tersebut lebih disebabkan oleh perbedaan struktur anatominya.

Kata kunci: Kekuatan lentur, bahan berlignoselulosa, kondisi pelunakan, struktur anatomi

I. INTRODUCTION

Curved wooden, bamboo, and rattan products are generally applied to furniture products, as well as to residential building components (door frames/windows), musical and sports instruments, toys, and other necessities. The conventional method of obtaining curved wooden products is done by cutting the wooden beams into a bent wood and connecting them to get the expected curve shape. Based on the process, this conventional method is easy to work because it only uses simple wooden techniques and tools. However, the deficiency and disadvantage of this traditional woodworking process is the wasting of wood raw materials, decreasing the wood strength due to fibre cutting, and reducing the beauty of wood fibre direction (Dwianto et al., 2019).

Bending straight solid wood is one possible solution in creating curvature shaped wood. Bending solid wood requires specific equipment and technique so that it needs basic knowledge of wood bending procedures. The wood bending mechanism is almost the same as a radial compression of wood (Dwianto, Inoue, & Norimoto, 1997). However, the length of the outer part of the curve must not change because it cannot receive tension forces to some extent so that the compression forces occur in the inner part longitudinally and radially. Therefore, the possibility is that it can be overcome by softening, deforming, as well as setting processes. Softening can be achieved by heating the wood in fresh, wet, high moisture content or water-saturated conditions (Hamdan, Dwianto, Morooka, & Norimoto, 2000; 2004). Deforming may be possible when the wood is in the softening phase. The setting is a drying process when the wood is in a deformed state to get the drying set.

Wood, rattan, and bamboo are lignocellulosic materials which consists of nature cellulose, hemicellulose, and lignin (Chen, 2015), and a mixture of natural polymers (Dotan, 2014) . The three main cell wall components contribute differently to the strength properties of the lignocellulosic materials. Hemicellulose is the bonding agent or cross-linking material between cellulose and lignin. Cellulose acts as reinforcement that provides tension forces and lignin for compression forces (Lum, Lee, Ahmad, Halip, & Chin, 2019). On the other hand, properties of lignocellulosic materials also depend on the anatomical structures and some other parameters (Asim, Saba, Jawaid, & Nasir, 2018). The chemical composition of cellulose, hemicelluloses, and lignin varies from one plant species to another, and even in different parts of the same plant (Li et al., 2014). Wood is a heterogeneous, hygroscopic, cellular, and anisotropic material. It consists of cells, and the cell walls are composed of micro-fibrils of cellulose (40–50%), hemicellulose (15–25%), and lignin (15–30%). Aside from the lignocellulose, wood consists of a variety of low molecular weight organic compounds, called extractives (Agneta, Kuckurek, Pyiatte, & EE, 1993). Rattan is composed of thick walled, heavily lignified parenchyma cells and vascular bundles (Weiner & Liese, 1998). Generally, rattan stem consists of holocellulose (71–76%), cellulose (39–58%), lignin (18–27%), and starch (18–23%) (Zuraida, Maisarah, & Maisarah, 2017). The cellulose and lignin contents correlate significantly with rattan strength. Higher cellulose content increases the modulus of rupture (MOR) of the rattan. Higher lignin content provides stronger bonds between rattan fibres. Physical (fresh and air-dry water contents, shrinkage and density) and mechanical properties (bending strength) are also taken into account when considering the utilization of rattan, particularly for large-diameter rattan (Olorunnisola & Adefisan, 2001). The three major chemical components of bamboo, which are cellulose, hemicelluloses and lignin, are closely associated in a complex structure (Khalil et al., 2012). Those three components are about 90% of the total bamboo mass, while the minor parts are pigments, tannins, protein, fat, pectin, and ash. Others include resins, waxes and inorganic salts. These constituents play an essential role in the physiological activity of bamboo and are found in the cell cavity. The chemical compositions of bamboo are known to be similar to that of wood, mainly consists of cellulose (±55%), hemicellulose and pentosan (±20%), and lignin (±25%) (Li, Wang, Wang, Cheng, & Han, 2010). Still, bamboo has a higher content of minor components compared to wood (Fazita et al., 2016). The composition varies based on years of growth, season, species, and the part of the culm.

Bend-ability of the wood or other lignocellulosic materials depends on their softening behaviour and viscoelastic property. The softening temperature of wood saturated with water has been reported by Becker & Noack (1968) to be between 80°C and 90°C in agreement with the glass transition temperatures for saturated modified lignin measured by Goring (1963). Lignin content of wood, rattan, and bamboo is in the range of 15–30% (Li et al., 2014), 18–27% (Zuraida, Maisarah, & Maisarah, 2017), and ±25% (Li, Wang, Wang, Cheng, & Han, 2010), respectively. Therefore, they can be softened at almost the same temperature. Viscoelasticity is a property of materials that exhibits both viscous and elastic characteristics when they are undergoing deformation (Meyers & Chawla, 2008). Viscous materials resist shear flow and strain linearly with time when a stress is applied. Elastic materials strain when stretched, and immediately return to their original state once the pressure is removed. Viscoelastic materials have elements of both of these properties and thus exhibit time-dependent strain. Whereas elasticity is usually the result of bond stretching along crystallographic planes in an ordered solid, viscosity is the result of the diffusion of atoms or molecules inside an amorphous material.

This research aimed to understand the softening behaviour and viscoelastic property of wood, rattan, and bamboo as lignocellulosic materials. The purpose was to observe why rattan and bamboo are more easily bent than wood, whether these are due to the softening behaviour of the chemical components or their anatomical structures. Static bending tests of wood, rattan, and bamboo were carried out in fresh, air-dried, and softened conditions by microwave heating to answer this question. Furthermore, the bending strength of wood, rattan, and bamboo was comparable, and a light microscope observed their anatomical structures.

II. MATERIAL AND METHOD

A. Samples Preparation

Nine years-old fast-growing teak wood (*Tectona grandis* L.f.), rattan (*Calamus* sp.), and 3 years-old andong bamboo (*Gigantochloa pseudoarundinaceae* (Steud.) Widjaja) were used for the experiments. Average diameter at breast height of teak tree and rattan stem was 40 cm and 3 cm, respectively. On the other hand, outer part diameter of the bamboo culm was 9 cm in the bottom and 7 cm in the upper part. Wood and rattan samples were cut 30 cm from the bottom, middle and the upper parts. Bamboo samples were taken from the 1st to 20th internodes.

Moisture content (MC) and air-dried density (ϱ) of the samples were measured from a sample size of 2 cm (length) x 2 cm (width) x 1 cm (thickness). Static bending tests were conducted from a sample size of 28 cm (length) x 2 cm (width) x 1 cm (thickness) to determine modulus of rupture (MOR) and modulus of elasticity (MOE) according to British Standard (1957). Especially the thickness of bamboo samples depended on their internodes along the culms.

B. Measurements of Physical and Mechanical Properties

Moisture content (MC) of the samples were measured by formula MC (%) = [(fresh weight – oven-dried weight/oven-dried weight) x 100%], and ϱ were obtained from ϱ (g/cm^3) = [air-dried weight/air-dried volume].

Static bending tests were carried out in fresh (as control samples), air-dried, and softened by microwave heating. Microwave heated the fresh samples for one minute, which was wrapped by heat-resistant plastic to soften the samples. The average temperature inside the microwave was 120°C. The MOR and MOE values were calculated using the formula MOR (kg/cm^2) = [(3*PL*)/(2*bh*^{2})], and MOE (kg/cm^2) = [(Δ*PL*^{3})/(4Δy*bh*^{3})], where *P* = load (kg), Δ*P* = load difference (kg), *L* = span (cm), Δ*y* = deflection (cm), *b* = sample width (cm), and *h* = sample thickness (cm). For bamboo samples, loading direction was conducted in the inner part with adjustment span (*L*) according to their thickness. All the measurements were carried out with three replications. The normalized values of MOR and MOE were calculated from MOR and MOE values of air-dried or softened conditions divided by that of fresh conditions in the same ϱ.

C. Anatomical Structure Observations

The transversal section of the samples was cut by a sliding microtome to a thickness of 20 µm then dehydrated with 30%, 50%, 70%, and 96% alcohol, carboxyl, and toluene, respectively. The sectioned transverse surface then was mounted with entellan (Dwianto et al., 2019) The images of each section were captured with a light microscope (Olympus BX-51) equipped with a digital camera (Olympus DP 73).

III. RESULTS AND DISCUSSION

A. Result

Figure 1 shows moisture content (MC) of fresh wood, rattan, and bamboo. MC of middle parts for both wood and rattan was higher than of the bottom and upper parts. However, their average MC was extremely different, i.e. 103.16% and 211.42%, compared to bamboo respectively. On the other hand, it naturally decreased from 54.35% in the bottom (1st internode) to 37.75% in the upper parts (20th internode) for bamboo.

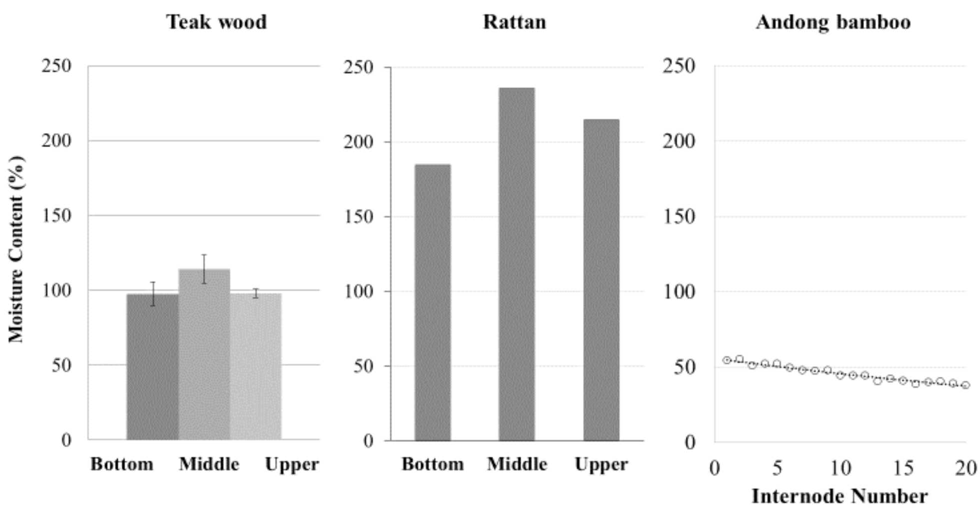

Figure 1. The moisture content of fresh wood, rattan, and bamboo

Figure 2 shows air-dried density (ϱ) of wood, rattan, and bamboo, in equilibrium moisture content (EMC). The ϱ varied in the bottom, middle, and upper parts for wood and rattan samples. The average ϱ of wood was slightly higher (0.55 g/cm^3) than that of rattan (0.48 g/cm^3). However, it remarkably increased from 0.48 g/cm^3 in the bottom (1st internode) to 0.74 g/cm^3 in the upper parts (20th internode) for bamboo.

Figure 3 and 4 show modulus of rupture (MOR) and modulus of elasticity (MOE) of fresh, air-dried, and microwave-heated (MW) wood, rattan, and bamboo. MOR and MOE values of wood, rattan, and bamboo increased from fresh to air-dried and decreased by microwave-heated.

When compared at the range ϱ from 0.48 to 0.55 g/cm^3, the average MOR of fresh wood, rattan, and bamboo samples were

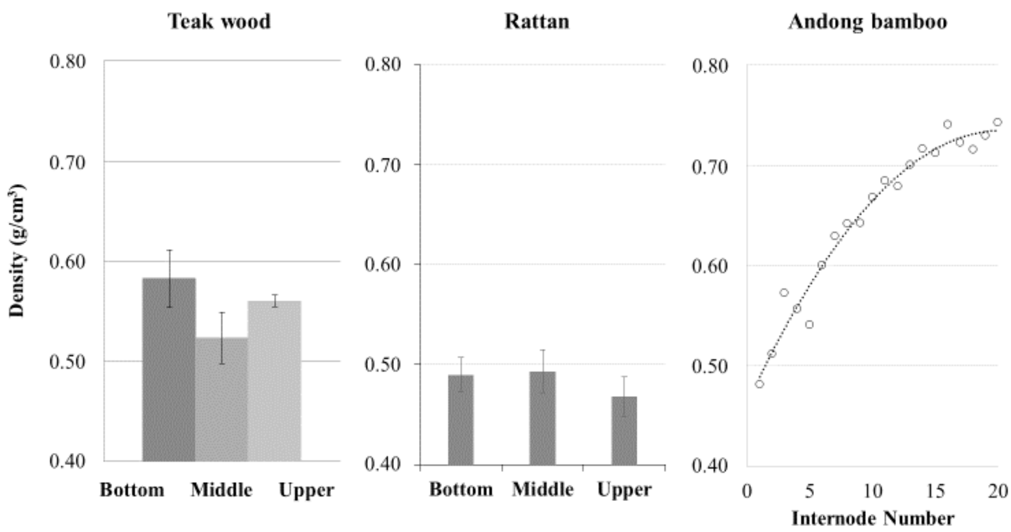

Figure 2. The density of air-dried wood, rattan, and bamboo

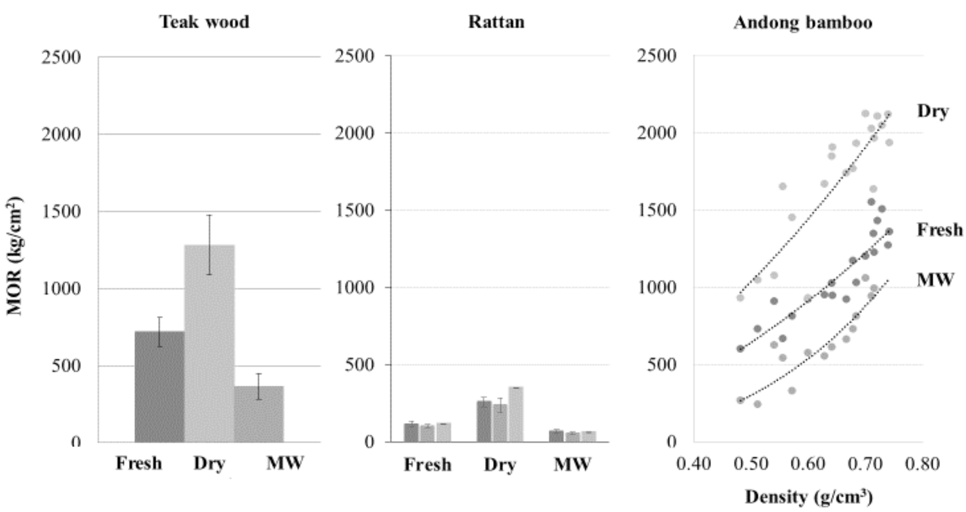

Figure 3. Modulus of rupture (MOR) of fresh, air-dried, and microwave-heated (MW) wood, rattan, and bamboo

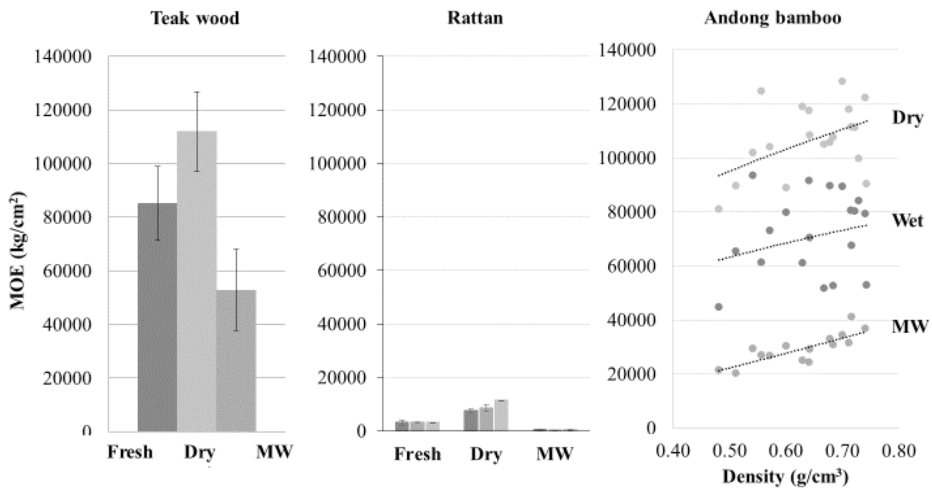

Figure 4. Modulus of elasticity (MOE) of fresh, air-dried, and microwave-heated (MW) wood, rattan, and bamboo

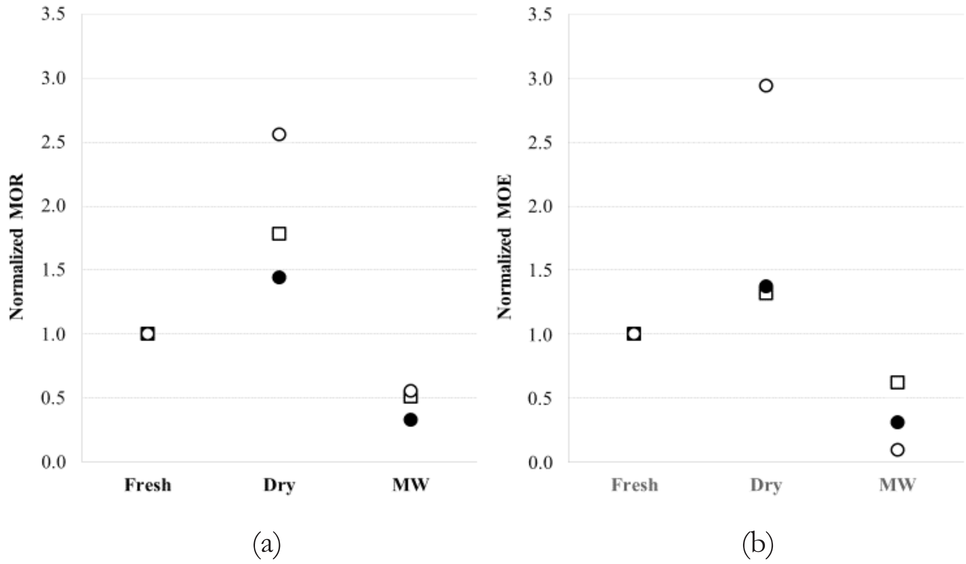

Figure 5. Normalized MOR (a) and MOE (b) values of fresh, air-dried, and microwave-heated (MW) wood (□), rattan (○), and bamboo (●)

717.59 kg/cm^2, 113.65 kg/cm^2, and 599.07 kg/cm^2 respectively. Drastically the increase was determined for the average MOR in air-dried rattan to 255.85 kg/cm^2 (increased by 125.12%). However, the decreasing of MOR was almost the same when they were softened by microwave heating for one min.

An average MOE of fresh, air-dried, and softened wood were 85,183 kg/cm^2, 111,948 kg/cm^2 (increased 31.42%), and 52,869 kg/cm^2 (decreased 49.29%), respectively. On the other hand, that for rattan were 3,092 kg/cm^2, 7,511 kg/cm^2 (increased 142.96%), and 302 kg/cm^2 (decreased 90.25%), respectively. As for bamboo were 44,685 kg/cm^2, 80,867 kg/cm^2 (increased 80.97%), and 21,436 kg/cm^2 (decreased 52.03%), respectively. Viscoelastic property of wood, rattan, and bamboo was more clearly compared by the normalized values of MOR and MOE in the same ϱ, as shown in Figure 5.

Drastically increased was determined for the average normalized MOR in air-dried rattan, i.e. 2.5 fold. However, the decreasing of all the average normalized MOR were almost the same, i.e. 0.5 fold when they were softened by microwave-heated, although the average normalized MOR of bamboo were slightly lower than wood in air-dried and microwave-heated. Significant improvement has also appeared for the average normalized MOE in the air-dried rattan, i.e. 3 fold and decreased to almost zero by microwave-heated. On the other hand, the average normalized MOE of wood and bamboo were similar.

Figure 6 shows the anatomical structures of teak wood, calamus rattan, and andong bamboo. The wood has rays, almost uniform cell wall thickness, vessels, lumens, and pores. Rattan and bamboo consist of vascular bundles surrounded by ground parenchyma tissues that have very thin cell walls, phloem, and large cavity of metaxylem. Specifically, the anatomical structures of rattan are unique with the presence of protoxylem, as shown in Figure 7.

B. Discussion

Remarkable differences in fresh MC of wood, rattan, and bamboo were considered due to their anatomical structures. Fresh MC exists as free water that is contained as the liquid in the pores or vessels, and as bound water that is trapped within the cell walls. Fibre saturation point (FSP), when the fibres are completely saturated with bound water may be roughly ±3% MC depending on the wood species, but 30% MC is the commonly-accepted average (Barkas, 1935). Mateo, Isabel, and María (2015) reported that the FSP of bamboo was 32% ± 3%. Although it is not well known, the FSP of rattan is likely to be similar to wood and bamboo. From the above experiment results, as FSP represented bound water within the cell walls, the free water of wood, rattan, and bamboo were approximately around 70%, more than 180%, and 10 to 20%, respectively.

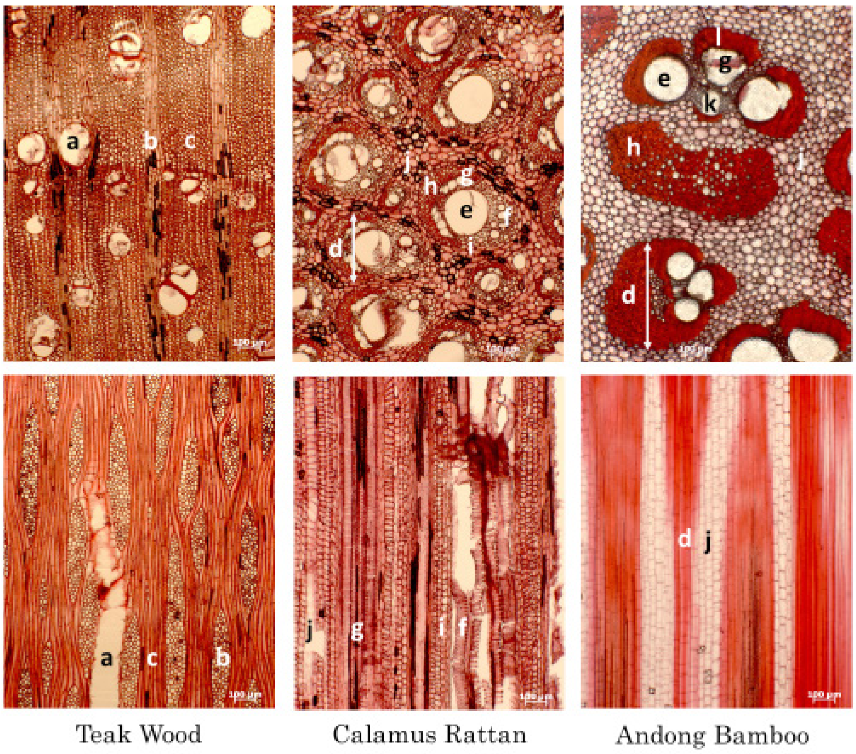

Figure 6. Anatomical structures of the wood, rattan, and bamboo

Remarks: upper: cross-section; bottom: longitudinal direction; a: vessel, b: rays, c: fibres, d: vascular bundle, e: metaxylem, f: protoxylem, g: phloem; h: fibre sheats, i: axial parenchyma, j: ground parenchyma, k: intercellular canal; l: sclerenchyma

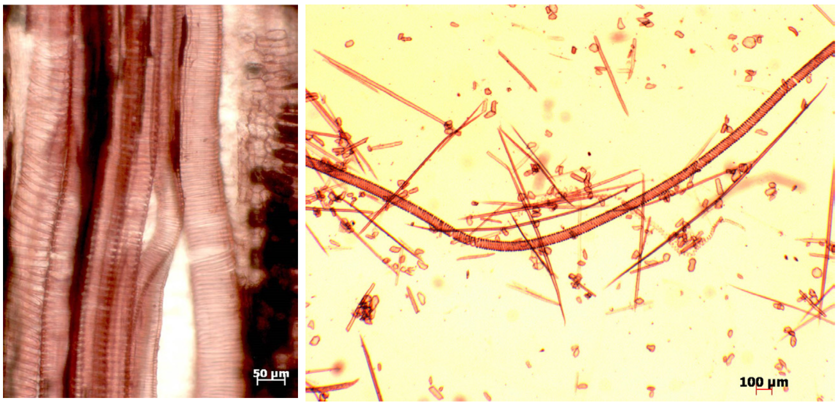

Figure 7. Protoxylem of rattan in the longitudinal direction

Nakajima et al. (2011) conducted the thermal softening behaviour of bamboo (*Phyllostachys bambusoides*) by submersing the specimens in a water bath under load and raising the temperature to 90°C, then cooling the bath to 20°C. They reported that the thermal softening behaviour of bamboo differs from that of wood (Japanese cypress - softwood), with a greater degree of residual deformation observed in the bamboo than in the wood. The high residual set of bamboo was associated with the thermal-softening properties of lignin (Nakajima, Furuta, & Ishimaru, 2008). Although they did not mention MC inside the specimens under loading condition, the result was in accordance with those previously stated that the softening temperature of wood saturated with water is between 80°C and 90°C (Becker & Noack 1968) due to the glass transition temperatures of saturated modified lignin (Goring 1963). MC is an essential factor in thermal softening behaviour and hygro-plasticization occurring under dry conditions (bound water) or moist conditions (free water) of wood fibre-based materials (Salmen, 1982). Since the remarkably differences in fresh MC of wood, rattan, and bamboo in the same ϱ was considered due to their anatomical structures, the difference in softening speed between wood, rattan and bamboo was caused by their MC.

The density of wood, rattan, and bamboo was also depended on their anatomical structures. Wood ϱ is mainly determined by the relative thickness of the cell walls and the proportions of thick- and thin-walled cells present. The average ϱ of 9 years-old fast-growing teak wood was 0.55 g/cm^3, lower than that of 60 years-old conventional teak wood, i.e. 0.67 g/cm^3 (Adi et al., 2016). It was probably due to the proportion of juvenile wood towards the upper and inner parts of the stem (Bowyer, Shmulsky, & Haygreen, 2003; Panshin, Zeeuw, & Brown, 1980). Kadir (1997) reported that the ϱ of *Calamus scipionum* ranged from 0.40 to 0.83 g/cm^3. The average ϱ of rattan used in this experiment was within this range, i.e. 0.48 g/cm^3. The ϱ of rattan was significantly correlated with height, the maturity of the stem and anatomical properties. Zhang, Shenxue, & Yongyu (2002) reported that the basic ϱ of bamboo was in the range of 0.40 ~ 0.80 g/cm^3. They argued that the basic ϱ of bamboo mainly depended on the ϱ of vascular bundles and their composition. As a rule, the ϱ of bamboo stem increased from inner to the outer part, and from the lower to the upper part. Kabir, Bhattacharjee, and Sattar (1993); Patel, Maiwala, Gajera, Patel, and Magdallawala (2013; and Sattar, Kabir, and Bhattacharjee (1990) reported that the ϱ of bamboo varied from 0.50 to 0.80 g/cm^3 depending on anatomical structures such as quantity and distribution of fibres around vascular bundles, with its maximum ϱ usually obtained from 3 years old mature culms.

MOR and MOE values of wood, rattan, and bamboo increased from fresh to air-dried and decreased by microwave-heated. Drastically increase was determined for the MOR and MOE in air-dried rattan. However, the lowering of MOR and MOE values were almost the same for wood, rattan, and bamboo when they were softened by microwave-heated. These results indicated that rattan was more easily bent, followed by bamboo and then wood. The MC of the lignocellulosic materials and microwave heating played an essential role in softening condition. Hydrothermal properties of chemical components significantly affected the changes of strength (MOR) and elastic properties (MOE).

Specifically, viscoelasticity is a molecular rearrangement. When a stress is applied to a viscoelastic material, part of the long polymer chain change positions. Polymers remain a solid material even when these parts of their chains are rearranging in order to accompany the stress. As this occurs, it creates back stress in the material. When the original stress is taken away, the accumulated back stresses will cause the polymer to return to its original form (McCrum, Buckley, & Bucknall, 2003). The secondary bonds of a polymer constantly break and reform due to thermal motion. Application of stress favours some conformations over others, so the molecules of the polymer will gradually flow into the preferred conformations over time (Dotan, 2014). Because thermal motion is one factor contributing to the deformation of polymers, viscoelastic properties change with increasing or decreasing temperature. In other words, it takes less work to stretch a viscoelastic material an equal distance at a higher temperature than it does at a lower temperature. Both wood and cellulose materials are involved in such materials and the viscoelasticity which causes a variety of mechanical properties is closely related to thermal motions of a polymer chain of the material.

Semi-crystalline cellulose exhibits a broad transition region and thus displays a gradual softening at increasing moisture contents (Salmen, 1982). The crystallites restrict the motion of the tie molecules between the crystallites in the microfibrils and thus shift the transition in these regions to higher temperatures or higher moisture contents. For the amorphous carbohydrates, the plasticizing effect of water is estimated from a free volume. The cellulose microfibrils act as the reinforcements in a matrix of hemicelluloses. Therefore, the softening effect due to water immersion results from a softening of the disordered zones between the cellulose crystallites in the microfibril. Under these conditions, the fibre is best represented by a discontinuous reinforced system in which only the cellulose crystals act as reinforcing elements.

Under both dry and water-immersed conditions, apparent activation energy has been obtained for the glass transition of lignin. It is concluded that the changes in elastic properties of lignocellulosic materials with increasing moisture content are determined by a softening of the amorphous carbohydrates. The structural rigidity of wood fibres and fibre products is greatly influenced by the stiffness of their main polymeric components: cellulose, hemicelluloses and lignin (Zuraida et al., 2017). It is essential to take these variables, temperature, and water content into account when predicting the mechanical behaviour of cellulosic materials as they are responsible for the significant changes in the properties of the matrix in these structures.

Wood is composed mostly of hollow, elongated, spindle-shaped cells that are arranged parallel to each other along the trunk of a tree. The characteristics of these fibrous cells and their arrangement affect strength properties, appearance, and resistance to penetration by water and chemicals, and many other features. The stem of rattan consists of the vascular bundle with one metaxylem vessel, two phloem fields, and protoxylem. The parenchyma and fibres are other cells encompassing the vascular bundle. Metaxylem vessel is the largest cell in

Calamus species, with an average diameter of 300 to 350 μm (Weiner & Liese, 1998). Any surrounding water could easily penetrate these voids. The tissues of bamboo stem include surface system (epidermis, subcutis, cortex), fundamental system (underlying tissues, pith rings, piths) and vascular system. The surface system is the bamboo skin, located in the outermost part, pith rings and pith located in innermost part. They form the outer and inner surface layers of the stem wall they are closely protecting the underlying tissues, and vascular system. Vascular bundles are distributed among the underlying tissues of the stem wall, and their density decreases from the outer side of the stem wall to the inner side (Zhang et al., 2002).

The deformation mechanism of bentwood cell walls is similar to that of compressed wood. However, the deformation of bentwood cell walls occurs mostly in the longitudinal direction (bending deformation), and that of compressed wood happens in the radial direction (compressive strain). The levels of bending deformation or bend-ability of the lignocellulosic materials depend on their cavities that could be deformed. In case of woods, they have rays and almost uniform cell wall thickness which strengthens their bending strength, even in softening condition. Therefore, the bend-ability of the woods depending on the portion of their vessels and lumens. Significant differences of the anatomical structure of rattans and bamboos to woods consist of vascular bundles surrounded by ground parenchyma tissues that have very thin cell walls. The metaxylem in vascular bundles of both bamboo and rattan strengthen their bending strength.

These anatomical observations indicated that rattan was more easily bent, followed by bamboo and then wood, due to the presence of protoxylem as a significant factor. Furthermore, the proportion of parenchyma cells and large cavity of metaxylem and phloem in rattan and bamboo were considered as parameters of their bend-ability. In addition, very thin parenchyma cell walls are more easily softened by microwave heating. Therefore, the differences in bending strength of wood, rattan, and bamboo were more likely due to differences in their anatomical structures rather than chemical components.

IV. CONCLUSION

The softening behaviour and viscoelastic property of wood, rattan, and bamboo have been studied by static bending tests in fresh, air-dried, and softening conditions to determine MOR and MOE values. MOR and MOE values of wood, rattan, and bamboo increased from fresh to air-dried condition, and decreased by microwave heating. The drastic increase was observed for the MOR and MOE values in air-dried rattan and dropped to almost zero by microwave heating. These results indicated that rattan was more easily bent, followed by bamboo and then wood. The MC of the lignocellulosic materials and microwave heating played an essential role in softening condition. Hydrothermal properties of chemical components significantly affected the changes of strength (MOR) and elastic properties (MOE).

The proportion of parenchyma cells and large cavity of metaxylem and phloem in rattan and bamboo, and the dimension of protoxylem in rattan were considered as parameters of their bend-ability. In addition, very thin parenchyma cell walls are more easily softened by microwave heating. Therefore, the differences in bending strength of wood, rattan, and bamboo were more likely due to differences in their anatomical structures rather than chemical components.

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SOCIAL CAPITAL IN MANAGING COMMUNITY PLANTATION FOREST: A CASE STUDY AT KPH BOALEMO, GORONTALO PROVINCE

Sylviani, Aneka Prawesti Suka, Surati* and Dewi Ratna Kurniasari

Center for Research and Development on Social, Economy, Policy and Climate Change
Jl. Gunung Batu, No. 5 Bogor, West Java, Indonesia

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SOCIAL CAPITAL IN MANAGING COMMUNITY PLANTATION FOREST: A CASE STUDY AT KPH BOALEMO, GORONTALO PROVINCE. Community Plantation Forest (HTR) is one among alternatives expected to fulfil the needs of timber. Limited capital, which is simply known as financial capital, is considered as the main problem in HTR development. However, there is also other capital but less known and understood namely social capital. This study aims to determine the social capital that can be utilized in HTR management. The study was conducted in Rumbia Village, Boalemo District, Gorontalo Province. The data collected were analyzed using a descriptive qualitative method in three steps: data reduction, data display and verification. In this study, the social capital is discussed in its dimensions of trust, norm, and network, which can improve the efficiency of society by facilitating coordinated action. Results of the study show that strengthening social capital in its dimension of trust, norm, and the network would encourage independence of both the farmers and forest farmer groups in HTR management. If the social capital does not work properly, the gap among farmers could occur and even becomes a barrier or limits in the involvement of members of the farmer group in the management of HTR. The farmers had a high trust for forestry extension workers. It became a dimension of social capital that should be developed further in HTR management to reach optimal benefits from HTR. Besides, the farmers also had high compliance to social norms of traditions, religion, and customary rules. The social capital held by the farmers should be appropriately addressed by the local and central government to develop successful HTR management.

Keywords: Social capital, community plantation forest, forest farmer groups, Boalemo

MODAL SOSIAL DALAM PENGELOLAAN HUTAN TANAMAN RAKYAT: STUDI KASUS DI KPH BOALEMO, PROVINSI GORONTALO. Hutan tanaman rakyat (HTR) merupakan salah satu alternatif yang diharapkan dapat memenuhi kebutuhan kayu. Keterbatasan modal, yang secara umum dipahami sebagai modal keuangan, dianggap sebagai permasalahan utama dalam pengembangan HTR. Namun demikian sebanarnya ada modal lain yang belum banyak diketahui dan dipahami oleh banyak pihak yaitu modal sosial. Penelitian ini bertujuan untuk mengetahui modal sosial yang dapat digunakan dalam mendorong keberhasilan pengelolaan HTR. Penelitian dilakukan di Desa Rumbia, Kabupaten Boalemo, Provinsi Gorontalo. Data yang dikumpulkan dianalisis menggunakan metode deskriptif kualitatif melalui tiga langkah, yaitu reduksi data, penyajian data dan penarikan kesimpulan. Dalam penelitian ini, modal sosial dibahas dari dimensi kepercayaan, norma dan jaringan yang dapat menigkatkan efisiensi masyarakat dengan memfasilitasi tindakan yang terkoordinasi. Hasil penelitian menunjukkan bahwa penguatan modal sosial yang berupa kepercayaan, norma, dan jaringan akan mendorong terciptanya kemandirian baik bagi petani maupun kelompok tani. Modal sosial yang tidak berfungsi dapat menimbulkan kesenjangan antar petani dan bahkan menjadi penghambat atau membatasi keterlibatan anggota kelompok tani dalam pengelolaan HTR. Petani juga memiliki kepercayaan yang tinggi kepada penyuluh kehutanan. Hal tersebut penting untuk terus dipelihara agar pendampingan melalui penyuluh kehutanan dapat mendorong pembangunan HTR secara optimal. Petani juga memiliki kepatuhan yang sangat tinggi terhadap norma sosial baik itu terhadap tradisi masyarakat, aturan agama ataupun aturan adat. Modal sosial yang telah dimiliki oleh anggota kelompok tani tersebut harus disikapi oleh pemerintah daerah dan pemerintah pusat dalam rangka mendorong keberhasilan pembangunan hutan tanaman rakyat.

Kata kunci: *Modal sosial, hutan tanaman rakyat, kelompok tani hutan, Boalemo*

* Corresponding author: tatisurati@yahoo.co.id

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I. INTRODUCTION

Social forestry policy through community plantation forest (HTR) scheme provides opportunities and legal access to the community in forest development activities through permit of management (Rumboko, Race, & Curtis, 2013). The HTR program is expected to meet community needs of wood, but capital, technological knowledge and human resources in management being an obstacle (Subarudi, 2014; Sanudin, Awang, Sadono, & Purwanto, 2015). Limited capital, which is simply known as financial capital, is considered as the main problem in HTR development. However, there is also other capital but less known and understood namely social capital.

The concept of social capital has been popularized by Putnam (1993) who defined social capital as part of social organization, such as trust, norms and networks, which can improve the efficiency of society by facilitating coordinated action (Field, 2003). In line with this, Schoones (1998) stated that social capital includes the ability to fulfil livelihoods through social networks and relationships such as cooperation, trust, and social security. Moreover, DFID (1999) Social capital has also included social capital as one of the five assets that build a sustainable livelihood framework. The weak can dim the spirit of mutual cooperation, exacerbate poverty, increase unemployment, crime, and hinder any efforts to improve the welfare of the population, including in the management of natural resources (Inayah, 2012 in. Shabrina, 2015).

Some of the research related to social capital include the relationship between social capital and the use and conservation of protected forests (Ekawati & Nurrochmat, 2014), social capital related to community forest management in Kulon Progo District (Hanurjoyo, 2015) and in Wonogiri District (Achmad, 2015), Social capital in managing mangrove ecotourism area by the Muara Baimbai community (Situmorang, 2018) and Pati District (Suka, Oktalina, & Irawanti, 2018), forest resource management in customary community of Kasepuhan Banten Kidul (Saputro, 2006), social capital related to conflict resolution and community welfare around the KHDTK (Desmiwati, Pribadi, & Maharani, 2018; Wakka & Bisjoe, 2018) and social capital related to agroforestry and tourism for the welfare of the people in Malang District (Lestari et al., 2018; Parmawati, Soemarno, & Sih Kurnianto, 2019).

Based on research by Febriani, Darusman, Nurrochmat, and Wijayanto (2012) stated that community participation is also a social capital in the successful implementation of HTR policies. The higher the social capital owned by the community, the more citizens or community groups involved in the community organizations. Asmin (2017) also stated that local knowledge provides a cognitive and instrumental foundation for the construction of social capital in the management of natural resources at the local level, including in the management of forest resources. Forestry institutionalization in terms of a culture of planting among the community through reforestation and rehabilitation, conservation, sengon planting programs and other planting movements is an essential social capital for the success of HTR (Hakim, 2009). The role of collaborating stakeholders provides knowledge to be understood about HTR policies through implementation efforts, socialization to communities around forests related to the social, economic and cultural characteristics of the local community, including an understanding of social capital owned by the community (Andrasmoro & Nurekawati, 2017; Andrasmoro & Nurekawati, 2017).

From these various studies, there is still little research on social capital related to HTR areas. This research aims to determine the social capital that can be used for HTR management, in the expectation that HTR can develop and improve the standard of living of farmers, especially in the research location, Rumbia Village. Result of the research is also expected to be inputs for Forest Management Unit (KPH) of Boalemo to encourage the development of HTR in the region.

II. MATERIAL AND METHOD

A. Research Location

The research was conducted in Rumbia Village, Botumoito Sub-district, Boalemo District, Gorontalo Province. Rumbia Village is within the working area of KPH Boalemo. The village has two forest farmer groups (KTH) that have received HTR permission since 2012, namely KTH Harapan Jaya 1 and KTH Harapan Jaya 2. This research was conducted in February 2018 with the primary respondents were farmers from KTH Harapan Jaya 1 and Harapan Jaya 2. HTR permit has been granted since 2012, with an area 142 hectares for KTH Harapan Jaya I and 137 hectares for KTH Harapan Jaya II. Each group consisted of 10 permit holders based on the Boalemo District Head's Decree in 2012, and there are 20 HTR permit holders. From the area of HTR given access to management, it is divided to each KTH member based on a joint decision, with the land area varying between households, which is between 4 and 8 ha.

B. Data Collection

Data collection included primary data at the village level and secondary data at the provincial, district and village levels (Table 1). Primary data were focused on the community's understanding of the program and the implementation of HTR development. Secondary data were collected in the form of data about the management of HTR (forest area, plant species, farmer group) and village monographs. Research respondents consisted of related parties, including government agencies (KPH Boalemo, Provincial Forestry Service, district government, and village government), community leaders, and village community members of farmer groups. Data collection was carried out by means of focused discussion and in-depth interviews with community leaders and farmers, discussions with representatives of relevant government agencies and recording data in government agencies, and field observations. The two KTHs granted HTR permit, every 1 HTR permit holder represents several farmers, then from a total of 20 HTR permits issued, there are 90 farmers involved in managing the HTR area granted by the government. In-depth interviews were conducted with respondents of 30 farming families from Rumbia Village, who were the members of both KTHs. The selection of respondents was made purposively, which represented various levels of community welfare to reflect the real conditions of the community in Rumbia Village.

Field observation was intended to get a picture of the condition of forest, settlement, daily life and interaction among fellow community member, as well as how people manage the environment. The research subject was KTH member who had HTR permit. The object of this research is HTR in Rumbia Village in the application of social capital by using three dimensions of the theoretical framework, namely trust, norm, and network.

C. Analysis

This research is a qualitative descriptive study. This research implemented procedure

Table 1. Method of data collection

No.	Method	Data source/ Respondent	Location
1.	Recording	Government institution, official reports	Province, district, village
2.	In-depth interview	Government institution, key persons, farmer group members	Province, district, sub-district, village
3.	Field observation	Land condition, species, management technique of HTR, condition of the community	Village
4.	Focus Group Discussion	Stakeholders and farmer group members	Province, district, village

that produces descriptive data in the form of written or spoken words from people and observable behaviour (Moleong. 2011) Before data analysis is performed, data testing is first performed to ensure the validity of the data obtained. The data testing method used is data triangulation. Triangulation is a data validity checking technique that uses something else in comparing the result of the interview with the research object (Moleong, 2011). Triangulation of data used in this study was a triangulation of source, by cross-checking answers between research informants. Interview with respondent was triangulated with each other to find out the validity of the data and the consistency of the results of interviews with related parties including the head of the KTH, village officials, resource persons from KPH Boalemo and the Provincial Forestry Services. Referring to Miles and Huberman in Sugiyono (2012) this study uses three steps in data analysis, namely data reduction, data display and conclusion drawing (verification).

In accordance with the definition of Putnam (1993) as cited in Field (2003) as above mentioned, three main pillars in social capital are trust, norms, and networks. In this study, following Putnam's (1993) definition in Field (2003), the discussion of social capital is carried out from the dimensions of trusts, norms, and networks. The level of trust, norms and networks is measured by giving respondents some structured questions. Answers from all respondents were calculated and averaged.

III. RESULTS AND DISCUSSION

A. Overview of Research Location

Boalemo District is a district in Gorontalo Province with an area of 1,829 km^2, with mostly hilly topography. Botumoito is the largest sub-districts in Boalemo with an area of 486.24 km^2 (26.59%). Botumoito is mainly a coastal area with Rumbia Village as the only village that has hilly topography with an average altitude of 18 meters above sea level. The total area of Rumbia Village is 76 km^2. According to Statistics of Boalemo Regency (2018), in 2017, the population of Rumbia Village was 1,906 consisting of 975 men and 931 women and 555 households. The livelihood of community in Rumbia Village was mostly from on-farm activities.

In Rumbia Village there are two farmer groups holding permits for managing community forest plantations (IUPHHK-HTR) obtained based on the Decree of the Regent of Boalemo in 2012. The farmer groups are Harapan Jaya I with an area of 142.02 ha and Harapan Jaya II with an area of 137.19 ha. The farmer groups received assistance from the central government for 8,000 jabon seedlings (*Anthocephalus cadamba*) to be planted on the HTR land. Unfortunately, the seedlings arrived in the dry season and at the village office without operational costs for planting. Meanwhile, the HTR land is located on the hills with difficult access and far from settlements. These conditions made it difficult for farmers to plant all the jabon seedlings and therefore, they plant some seedlings in their own land which are near from their settlement. Because seedlings came in the dry season, many seedlings eventually die because they cannot stand the heat. This experience has caused farmers to lose motivation to grow trees and get involved in the HTR program. Other reasons from the farmers were the lack of socialization from the local government about the HTR program and the ease of getting timber from surrounding forest areas.

The motivation of the community to rerun the HTR program reappeared driven by the success of a local farmer who sold 30 jabon trees from his land for IDR 20 million-plus a motorbike. For the future, the HTR program is expected to be sustainable, given that in 2019 the farmer groups were currently receiving assistance from the government in the form of nursery program. Seedlings from the nursery can later be planted both on privately owned and HTR lands. The seeds given include jabon, durian, rambutan and cloves. The location of the HTR, which is the hilly area is more suitable for planting timber species rather than to coconut as the main local commodity. Growing timber to prevent erosion could also become savings for the future.

The process of dividing land area management by each KTH member is carried out by mutual agreement between the members of the KTH. Communal natural resource management arises when there is an agreement on joint utilization among its members. This agreement can occur from the regular and continuous interactions between community members in using the resources. Collective actions within the community would appear when social capital is available in a community (Prasetiamartati, Fauzi, Dahuri, Fakhrudin, & Lange, 2006). The existence of social capital can play a role as a glue for the community (Stone & Hughes, 2002). The strength of social capital can be known through the elements inherent in the social structure of the society which subsequently becomes a source of energy for its citizens (Abdullah, 2013). In accordance with the definition of Putnam (1993) as cited in Field (2003) as above mentioned, three main pillars in social capital are trust, norms, and networks.

B. Stakeholders Trusted by Farmers

Taking Putnam's definition, the most non-transferable dimension of social capital is trust. Trust is a product of social capital, not a product of its components. The dimension of trust discusses the expectations that arise in a community that usually behaves, honestly, cooperatively, and based on shared norms, for the benefit of other members of the community (Hadisurya, 2017). According to Inayah (2012) in Sabrina (2015) social capital is a requirement for human development, economic development, social, political and democratic stability, including the management of natural resources. The main determinant of various problems and irregularities that occur in many countries is limited to social capital that grows in society. The lack of mutual trust between communities can cause difficulties in facing social and economic vulnerability (Rijal, 2013; Lestari et al., 2018). Trust arises when both parties already believe in each other, so they are willing to share resources without worrying that the resources will only be used by one of the parties. When a relationship established, the trust will arise (Tsai & Ghosal, 1998 in Luciana & Margadinata, 2017). Positive community perceptions also influence the success of a program; hence they are willing to be involved in the program (Novayanti, Banuwa, Safe'i, Wulandari, & Febryano, 2017). Thus, the trust of the community is needed to be able to accept the HTR program for smooth implementation in the field; community will take HTR when they are assured on the importance and benefits of HTR.

The research results showed that 100% or all respondents in Rumbia Village believed that the forest could sustain their livelihoods economically, aesthetically, and conservatively. From the economic perspective, it can be seen from the increase of income, while aesthetics and conservation can be seen from the presence of the forest, so the environment is green and protected from floods. They know that the forest could provide lots of benefits from both timber and non-timber products for the surrounding forest community. Currently, farmers still apply extensive land-use system and have not yet implemented intensive farming. Therefore, farmers can have several plots of farmland in several locations, both on privately owned and on HTR land. The common land ownership in Rumbia Village was 8 hectares per farmer household (primary data).

Not only farmers, many stakeholders could involve in forest management. Here, social capital emerged as a form of social relations among stakeholders involved in forest management which could further support the successful implementation of the HTR program. Social capital becomes the glue of togetherness in the community and also with the outsiders (Stone & Hughes, 2002). The level of farmers' trust in various stakeholders is presented in Table 2. These stakeholders are fellow farmer,

Table 2. Level of trust of the farmers toward stakeholders who can help in forest management (%)

Stakeholders	Level of trust (%)
Fellow farmer	83
Community leader	83
Farmer group administrator	94
Farmer group	90
Village government	90
Village officer	80
Local government	77
Extension workers	100
Counterpart (NGO, foundation, university, etc.)	57
Financial institution	40
Trader	70
Broker	43
Industry	77

community leader, farmer group administrator, farmer group, village government, village officer, local government, extension workers, counterpart (NGO, foundation, university, etc.), financial institution, trader, broker, and industry.

Table 2 shows that extension workers were the most trusted stakeholder to help farmers manage the forests with a confidence level of up to 100%. This is because the extension workers are the main actor who can interact directly with the community. The stakeholders who also gained high trust by over than 80% were farmer group administrator, farmer group and village government, fellow farmer and community leader as well as village officer. Therefore, if there are any programs related to forest management, including the HTR, these stakeholders need to be involved in the implementation of the program. Any program, information and innovation will be more easily accepted by farmers if delivered by these stakeholders as the trusted parties. Hasbullah (2006) stated that actions based on firm trust will increase community participation. Furthermore, considering the high level of farmer trust, especially for extension workers, capacity building, skills and facilitation for extension workers are needed to assist farmers in managing land. Meanwhile, the farmers' lower trust in other stakeholders such as to financial institution, broker, and counterpart may appear because of the lack of relations between these parties and farmers so that farmers less felt their presence.

C. Social Norms

Norms are a set of rules that arise from the understanding, values, expectations and goals shared by a group. Norms can be sourced from religious values, morals, professional ethics, as well as secular values which are subsequently built and evolved as the history of certain social groups, progresses (Fukuyama, 1999). Norms can also in the form of formal and informal rules that allow for cooperation and coordination between community members to facilitate the achievement of the shared goals (Coleman, 1988). Norms are expected to be obeyed and followed by community members in a particular social entity. This norm usually contains social sanctions that can prevent individuals from doing deviations from regular habits in society (Luciana & Margadinata, 2017).

This research explores the models that exist in the community and have influences in forest management. The norms are grouped into religious norms, customs, traditions, regulations, and consensus. The research results revealed 57% of the farmers stated that there was consensus applied in managing their forest land. Meanwhile, the existence of customary norms, regulations, traditions, and religious norms in managing forest land was stated by 33%, 30%, 27%, and 23% of respondents, respectively. Furthermore, the existence of social norms has consequences of sanctions if certain norms are not implemented. These sanctions include that they will be harmed if they violate these rules, other sanctions in the form of legal sanctions. Among the five groups of social norms, regulation is the most widely known by 67% of farmers as the norm that has sanctioned, then followed by religious norms, customs and traditions. Meanwhile, even though 57% of the farmers applied consensus in managing forests, the agreement has the least sanctions or 47% compared to the sanctions of other social norms. The existence of various social norms and the sanctions in forest management is presented in Table 3.

Table 3. Existence of social norms and the sanctions to manage forestland

No.	Social norm	The presence (%)	Sanction (%)
1.	Religious norm	23	57
2.	Customs	33	50
3.	Traditions	27	50
4.	Regulations	30	67
5.	Consensus	57	47

Some forms of religious norms for the community in forest management include protecting nature, praying before starting to manage the forests, upholding rights and vanity, not polluting the environment, not cutting down trees, prohibiting deforestation because it can be troublesome for others, not making alcohol liquor from non-timber forest products, and not disturbing the ecosystem. According to Hakim and Wibisono (2017), one of the social capital that form a strong bond between the people is ritual and religious events, which are part of the process of cultural and religious customary activities. Some examples of the customs are obtained permission from customary leaders before planting and cutting as well as performing certain ceremonies before they enter the forest. Meanwhile, tradition appears in opening the land and fixing up the village begins in the form of praying, performing the *dayango* dance and seeing astrology to determine a good day. Also, local knowledge is used to find the best season and time for planning trees. Local wisdom helps the development of individual and group behaviour to interact with the environment and manage natural resources wisely (Yeny, Yuniati, & Khotimah, 2016).

In this research, the application of the community's social norms in forest management was measured based on the level

Table 4. Compliance level of the farmers to social norms (%)

No.	Social norm	Compliance level (%)
1.	Religious	100
2.	Custom	100
3.	Tradition	100
4.	Regulation	
	a. Farmer group rules	100
	b. Village rules	100
	c. Government rules	100
5.	Consensus	
	a. Appeals from a community leader	87
	b. Appeals from village officer	100
	c. Appeals from extension workers	100
	d. Appeals from NGO, university, etc.	57
	e. Appeals from investor, trader, industry	73

of farmers' compliance with the norms as presented in Table 4. Especially for regulations and consensus, more detail information was collected to find out which the farmers obeyed stakeholders. Farmers' compliance was very high up to 100% on religious norms, customs, traditions, farmer group rules, formal village rules, government rules, appeals from village officers, and appeals from extension workers. With such a high level of compliance, the existence of regulations and norms shared by these stakeholders can be developed for the advancement of HTR management in Rumbia Village. Communities are more likely to follow the rules, namely rules from farmer groups, formal village rules, and government regulations related to forest management. The farmers are generally also afraid of sanctions, although there were no written sanctions included in these rules. Compliance with these social norms needs to be supported by commitments ranging from village governments to local governments and the central government in the development of HTR.

D. Social Networks

Social capital enables the emergence of strategic and potential resources to be utilized by individuals and community groups in the form of a network of raw materials, markets, information and capital resources in resource management (Saleh, Sumardjo, Hubeis, & Puspitawati, 2018). In this research, farmers' networks in managing forests were grouped into technical aspects of forestry, marketing, capital, and institutions. Through these networks, we can see which stakeholders were the most often contacted or contacting the farmers in certain management aspects. Related stakeholders were classified into the head of the farmer group, administrator of farmer group, extension officer, village government, local government (including various affiliated offices), trader, and financial institution. The respondents also have the alternative to choose 'none' if they did not know to whom they should seek information when encountering problems, or if no one has ever contacted them in various aspects of forest management. The social networks are presented in Table 5 and 6.

As presented in Table 5, if there were technical problems in forest management, stakeholders contacted by the farmers were head of farmer group, extension officer, village government and local government (related offices). In marketing problems, stakeholders contacted by the farmers were traders, in institutional aspect were head of farmer groups, village governments and local governments (related offices), while in financial matters were trader and financial institution. However, there were also quite a lot of farmers who did not know to whom they have to deal with to solve various forest management problems. They had limited social networks. Around 94% of the farmers have limited capital networks, 81% have limited institutional systems, 70% have limited marketing networks, and 27% have

Table 5. Stakeholders contacted by farmer related to various aspects of forest management (%)

Stakeholder	Technical	Marketing	Institutional	Financial
Head of a farmer group	50	-	13	-
The administrator of the farmer group	-	-	-	-
Extension officer	10	-	-	-
Village government	7	-	3	-
Local government (related offices)	7	-	3	-
Trader	-	30	-	3
Financial institution			-	3
None	27	70	81	94
Total	100	100	100	100

Table 6. Stakeholders contacting farmer related to various aspects of forest management (%)

Stakeholders	Technical	Marketing	Institutional	Financial
Head of the farmer group	43	-	7	-
The administrator of the farmer group	3	-	3	-
Extension officer	10	-	3	-
Village government	3	-	-	-
Local government (related offices)	7	-	-	-
Trader	-	10	-	3
Financial institution	-	-	-	3
None	37	90	87	94
Total	100	100	100	100

limited network on technical forestry.

Table 6 shows stakeholders contacting farmers on various aspects of forest management. From the technical aspects of forestry, head of farmer group, extension officer, local government (related offices), farmer group administrator, and village government were stakeholders who made contact to the farmers. However, there were still 37% of farmers who stated that no one contacted them in technical forestry matters. The absence of stakeholders contacting farmers in terms of capital, marketing, and institutions was even higher. This indicates that farmers could be said as walking alone and do not have a network in various forest management activities.

The intensity of the relationship between the stakeholders with the farmers varies between once a month to once a year. But in general, the farmers said that the link was rarely carried out and only certain farmers had a high intensity of the relationship. Relationships were made through communication by cell phone, letters, and direct meetings. From Tables 5 and 6 above, it can be seen that the head of the farmer group was the main figure who was the most made contact to or contacted by farmers. This condition needs to be considered and used to convey various information, programs and innovations in the context of developing HTR and other government policies. On the other hand, limitations of farmers' networks in terms of capital, institutions and marketing need to get attention and find solutions to support the development of HTR as well as the welfare of the farmers.

E. Application of Social Capital in the Management of Community Forest Plantations

Social capital, in the form of trust, norms, and networks, can encourage the creation of independence, both as personal and as a group. However, gaps can also occur if social capital is not functioning, and can even become an obstacle or limit the involvement of farmers in HTR management. Quality of a society with high social capital is coloured by the existence of concepts, competencies, connections, credibility and care (Ancok, 2003). However, strengthening community capacity is still needed; hence existing social capital can be appropriately used and even continue to be improved. Some critical efforts to increase social capital could be made through training in group settings, character education, hospitality, formal and family education as well as interventions from stakeholders involved to improve the capacity and quality of community's livelihood.

From the research results, it is known that from the dimension of 'trust'', farmers trust the extension workers in facilitating forest management activities. The presence of extension workers in the community aside from being a supervisor of community activities and interactions with the forest can also increase community trust in extension workers (Samosir, Purwoko, & Herianto, 2015). Assistance for HTR permit holders is needed to support the smooth operation of HTR activities; however it turns out that the number of extension workers and mentoring material is still inadequate, for example as found at the KPH Gedong Wani, South Lampung District (Novayanti et al., 2017). The similar case related to the shortage of extension workers was also experienced in the study site, Rumbia Village, Boalemo District.

Meanwhile, compliance of the farmer to social norms was very high. On the other hand, their social networks are generally still limited, because there were still many farmers who did not know to whom they should make contact when dealing with problems in forest management related to forestry technical, marketing of forest products, capital and institutions. The limited number of extension workers will hamper forestry programs, including the BLU (Public Service Agency) program from the Ministry of Environment and Forestry, where members of farmer groups need intensive assistance to participate in the BLU program.

IV. CONCLUSION

Strengthening social capital in the form of trust, norms, and networks will encourage the creation of independence, both for respondents as individuals and groups. However, gaps will also occur if social capital is not functioning, even becoming an obstacle or limiting the involvement of farmers in managing HTR. High trust for extension workers is social capital that must be developed in the framework of HTR.

Compliance with social norms is very high both on community traditions, religious rules or customary rules. Farmers strongly obeyed appeals from village officials, extension workers and community leaders. Social capital that has been owned by farmers must be addressed and taken into account appropriately by the government in the context of HTR development.

The strategy that can be developed in the implementation of HTR policy in Boalemo District, Gorontalo Province is to optimize local government support in accelerating HTR implementation by more intensive conducting communication and assistance to each KTH. An extension worker is also needed so that forestry programs especially HTR or other social forestry schemes, can be implemented well in the community. Thus, it is expected to achieve social, economic and ecological goals.

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

Or

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

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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

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