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IKA HERIANSYAH

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Chairman : Hazandy Abdul Hamid, PhD
Faculty : Forestry

Tropical forests deliver all kind of ecosystem services to the society. Thus, increasing the value and sustainable use of forest ecosystems has significant economic implication while at the same time is an important step towards resource conservation and environmental protection.

The implementation of sustainable forest management (SFM) will ensure that the goods and services derived from the forest meet present-day needs. At the same time secure the continuous availability and contribution to long-term development, which will equalize the production goals with the environmental and social ones. However, forest use and management practices in the past which were concentrated more on timber production rather than forest services resulted in a number of environmental problems, such as land degradation, loss of biodiversity and greenhouse gas emission.

With respect to the shifting paradigm of forest management from timber-oriented to resource-based management, it stands to reason that the spirit to use the forest environmental services must be practically actualized and that carbon trade forms one of the promising potentials that need to be explored. To achieve this, we must be willing to conserve and manage the remaining forest resources on sustainable basis and to conduct extensive reforestation programmes in degraded lands.

In the term of managing forest resources on sustainable basis, achieving SFM requires environmentally responsible logging, hence the growing interest in reduced impact logging (RIL) as an alternative strategy to promoting good forestry practices in the tropics be expected can continue to fullfil the functions of forest ecosystems. Many studies implies that reduced impact logging (RIL) techniques greatly reduced damage to trees in the residual stand and reduced the amount of ground area disturbed by machinery. However, data and information on the characteristics of logged over forest and the suitability of RIL technique in the tropical forest is lacking. For these reasons, the study on effectiveness of RIL at the operational level and its impact on residual forest stand has been evaluated based on damage

level, disclosure area and production potential of residual forest stand related to sustainable yield (study 1).

The study of effective RIL technique in natural forests was conducted in several forest concessionaires in Indonesian Borneo, with focus on characterizing of forest structure and composition at different logging intensity. Forest inventories for both pre-harvested and post-harvested inventories were conducted at 100 ha area of each different logging intensity which determined based on harvested limit diameter, i.e. 40 cm, 50 cm and combination 40 and 50 cm. Pre-harvest inventories were conducted for all trees categories (diameter of 20 cm up), then mapping of trees, planning of roads and skidtrails, and determine directional felling. After harvesting, post-harvest inventories were conducted to calculate damage level and area of disclosure. Residual trees and damage trees was counted and used it to evaluate the effective of RIL technique at different logging intensity. Logging with applied harvest diameter limit of 50 cm resulted better condition of residual trees in term of number and volume, environmental friendly with lower damaged level and disclosure area compare to higher logging intensity with applied harvest diameter limit of 40 cm and combination of 40 and 50 cm. Residual stand can be recovered at the age of 35 years under D limit of 40 cm in primary forest, while 22 years of logged-over forest was not recovered, then residual trees need longer rotation of 57.3 to 63.2 years to achieve sustainable yield.

Since logging intensity greatly influence the effectiveness of RIL and stand density of residual trees was greatly influence to production potential, the number, limit diameter determination,distribution and crown condition of harvest trees as well as regulation of cutting cycle (rotation age) must be considered. Supervising and monitoring from government must also be done during logging operation to ensure that RIL technique applied on the right procedure, thus meet ecological and economical function of forest ecosystems.

In the field of logging, it is important to use the suitable harvesting system which complies with the principles of SFM, and in term of conducting extensive reforestation programme on degraded lands, achieving SFM requires suitable silviculture techniques through forest improvement or interventions, such as rehabilitation and restoration. Generally, however, suitable silvicultural treatments in nursery level as well as in operational level are limited and site specific. Lack of field data has been a barrier to proceed for evaluation of effectiveness of silviculture treatment on productivity changes in tropical degraded forests.

Reforestation program through reintroduce tree species lost, especially fast growing dipterocarp is implemented to curtail degraded lands, then the study is focused on *Shorea leprosula* as a promising species to be used for reforestation program and offers opportunities for enhancing carbon sink. *Shorea leprosula* is also as the dipterocarp family which make up most of the tropical forests of Southeast Asia that have been commercially logged for many years, then has suffered a massive population reduction mainly because of the rate of exploitation of its timber.

Restoring degraded logged-over forest which is indicated by low soil fertility and organic matter due to imbalance nutrient cycle are of paramount importance as there has been increasing attention towards these forest as the sustainable use of these resources. Organic matter has been identified as a key attribute in numerous soil properties and processes and important for productivity, community structure and fertility in terrestrial ecosystems. However, the influence of organic matter on soil depends on amount, type and size of added organic materials.

The study on application of organic material was conducted in nursery stage (study 2) to evaluate the different kind and application rate of organic materials on growth and biomass accumulation and to determine suitable application for restoration of degraded forest in the humid tropics of Peninsular Malaysia. Mineral soils from degraded lands were amended with different rates of organic materials, such as pulp mill sludge, compost, oil palm mesocarp and their combinations and application rate were 0, ⅓, ½, ⅔, and ¾ of v/v. Growth measurement was conducted in every month for early growth up to 3 months after application and continued for every three months, while biomass were measured on initial, 3-, 6- and 12-month after application by destructive sampling method. Plant growth and biomass accumulation was increased by all amendments, however applied sludge with application rate 67% and more will be raising mortality rate. Growth rate of *Shorea leprosula* increased with decreasing application rate of mix organic materials, consequently.Based on this study, restoration program in tropical degraded forest without applied organic material indicated poor growth rate and biomass accumulation, then organic material application to be one of the requirement treatments needed for better results. Compost as well as the type of past forest structure were important factors which resulted best growth performance with high survival rate and recommended for restorationtechnique in Tekai Forest Reserve, Pahang, Malaysia and other comparative areas. The study suggest that to successful restoration program, preliminary study in nursery stage have to be done first to assist the recovery of an ecosystem that is damaged, degraded, or destroyed.

Forest rehabilitation through forest plantations establishment serves to sequester large amount of carbon and are being consider as one of the reforestation options in order to reduce the increasing costs of wood from natural forests and also to decrease the pressure on remaining natural forests. Although the plantation has a potential of high productivity, it may have low yields and degrade the site if managed poorly. However, data and information on the factors that control the productivity of plantation and on ways of managing the site to maintain the productivity of successive tree crop are insufficient. Thus, the study on the effect planting design of multi-storied forest rehabilitation (study 3) and planting system (study 4) on productivity and biomass accumulation have been evaluate in order to meet the future demand of general utility timber and to combat global warming.

Multi-storied forest management (MSFM) is a promising rehabilitation technique to promote forest development and management in the tropics. MSFM was established in Chikus Forest Reserve, Perak in 1992 to convert marginally poor forest into forest plantations in order to meet the future

demand of general utility timber and to combat global warming. The experimental plots were set up to demonstrate five different planting designs, namely type A; one row of indigenous high quality timber species planted (*Shorea leprosula*) and one row of 3 years old exotic trees retained (*Acacia mangium*), 1:1, type B; 2:2, type C; 4:4, type D; 8:8 and type E; 16:16 in two different planting directions north to south and west to east. Each plot has an area of approximately one hectare with 3.0 m x 3.7 m spacing. The direction of planting row was not differed each other for both growth rate and survival. In the early growth up to 8 years old, diameter and height growth tends to be increase with number of row from type A to type E, except for tree height of type E, as a result of low inter-specific competition. At the age of 16 years old, *S. leprosula* was almost dominant in all planting designs of multi-storied forest and replacing the exotic species of *A. mangium.* The competition for both inter- and intra-specific was high as depicted by survival rate which decreased with increasing number of row from type B to type E as well as mean annual increment. The best performance of tree growth was type C, which is four rows of *S. leprosula* and four rows of *A. mangium* with 21.99 cm, 20.09 m and 66.4% of average diameter, total height and survival rate, respectively. The volume of best planting design was 152.23 m^3 ha^{-1} and the total biomass was 79.42 tonnes ha^{-1} (≈ 34.76 tonnes net C ha^{-1}), 59.62 tonnes ha^{-1} of aboveground biomass and 19.80 tonnes ha^{-1} of root biomass. The best planting design can absorp 124.97 tonnes net CO_2. The type C of planting design is recommended for optimum growth performance, stand productivity and capacity of CO_2 absorption in multi-stored forest management.The study was also derived specific equations (*tier 3*) and carbon content at different tree component and tree age through destructive sampling method. Biomass proportion were 56.88, 14.92, 3.48, and 24.85% for stem, branches, leaves and root, while average carbon content were 43.77, 42.63, 43.55 and 41.02%, respectively.

Shorea leprosula or called light red meranti was sound to be one of the promising species for reforestation as well as for replacing exotic species, however, this species has irregular pattern of flowering and short period of seed storage. Thus, vegetative propagule offers a feasible solution for seedling production. Data on vegetative propagule performance in the field is very limited and this has to be tested before recommended for large scale plantation establishment. In particular, no biomass studies have been done in the trees from stem cuttings.

The evaluation of potential production and biomass accumulation of 12-y old *S. leprosula* cuttings was carried out in Gunung Dahu Forest Research, West Java, Indonesia. Based on basal area distribution, destructive samplings of 18 representative trees in different spacing and planting types were also done. The results showed that the diameter and height growth and the proportion of canopy were found to have positive relationship with spacing regime except survival rate which was found to have negative relationship. Growth performance of this species in monoculture planted-system showed better results than the other in mix planted-system with pines for all spacing regimes, while the proportion of canopy was not different to each other. The regression models related to growth parameters, such as diameter (D) and

total height (H) to stem volume and biomass of tree component or combination of tree component were constructed. These models were then used to estimate stem and biomass accumulation for all stands. Production potential of 12-yr-old *Shorea leprosula* from stem cuttings are 154.85, 136.97, 38.95 and 83.22, 72.99, 48.41 m^3/ha for monoculture planted of 2 x 2, 3 x 3, 5 x 5 and mix planted with pine of 2 x 2, 3 x 3 and 5 x 5 m spacing, respectively and their total biomass accumulations are 89.89, 76.78, 24.27 and 49.74, 43.95, 30.05 ton/ha.

Based on study 4, individual trees responded to wider spacing and lower competition resulted greater individual production and biomass accumulation as well as diameter growth, which monoculture planting system tends to be higher in productivity than mix-planting system. The figure for production potential and biomass accumulation indicate that their quantifications can be estimated using only D and combination D-H for both specific and a stand equations.

Since forest productivity seems to be affected by suitable of species to site condition and planting technique, spacing, planting type, planting design and application of organic materials should be considered to ensure sustainability in producing high productivity and for future forest rehabilitation and restoration.

Based on study 1 to 4, data of forest inventories tend to be highly variable, especially in very diverse mosaic landscapes, in different forest-type and different silviculture treatments. The study has demonstrated the tested general allometric relationships are not as accurates forest type-specific allometric equation. Thus, converting forest inventory into volume, biomass and carbon of dipterocarp forest of Southeast Asia requires the development of specific allometric relationships (study 5). For this purpose, data were collected from several sites in Southeast Asia, both from man-made forests and natural forests. Trees sampled from man-made forests were smaller than 30 cm in diameter and chosen based on diameter distribution, while trees sampled from natural forest were bigger than 20 cm in diameter and chosen depending on normality of tree structure during operational felling activities of logging companies. In total, 119 sample trees with D ranging from 1.2 cm to 114.6 cm and H ranging from 1.9 m to 59.1 m were destructively. Examination of the model residuals of the forest type-specific equation (model A) indicated that using D alone as the predictor variable produced stable relationship, but the inclusion of H as a second predictor variable increased the performance of the model, both for stem volume and biomass. Biomass expansion factor was decreased with increasing D from 1.6 for D less than 10 cm to 1.2 for D more than 40 cm. The study have therefore compared with several general allometric equations resulted that general equations are not as accurate as forest type-specific equationfor estimating biomass in the dipterocarp forest of Southeast Asia. The forest-type allometric equation is recommended for use in the estimation of biomass and stem volume from inventory measurements. Therefore, using the equations, how much emission can be reduced from the REDD project and/or how much CO_2 can be absorbed from A/R and IFM project can be estimated more accurately and verifiable.

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Sebagai memenuhi keperluan untuk ijazah Doktor Filsafat

PENILAIAN TEKNIK PENGURUSAN HUTAN MAMPAN UNTUK PRODUKSI BIOJISIM DAN SEQUESTRASI KARBON

Oleh

IKA HERIANSYAH

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Pengerusi : Hazandy Abdul Hamid, PhD
Fakulti : Perhutanan

Hutan tropika menyediakan semua jenis perkhidmatan ekosistem kepada masyarakat. Oleh itu, meningkatkan nilai dan penggunaan ekosistem hutan secara mampan mempunyai implikasi ekonomi yang penting dan pada masa yang sama merupakan satu langkah penting ke arah pemuliharaan sumberdaya dan perlindungan alam sekitar.

Pelaksanaan pengurusan hutan secara mampan (SFM) akan memastikan bahawa barang-barang dan perkhidmatan yang diperolehi dari hutan memenuhi keperluan masa kini. Pada masa yang sama ia akan menjamin ketersediaan berterusan dan sumbangan kepada pembangunan jangka panjang selaras dengan matlamat pengeluaran, alam sekitar dan sosial. Walau bagaimanapun, penggunaan hutan dan amalan pengurusan pada masa lalu yang tertumpu lebih kepada pengeluaran kayu dan bukan perkhidmatan hutan menyebabkan beberapa masalah alam sekitar, seperti kemusnahan tanah, kehilangan biodiversiti dan pelepasan gas rumah hijau.

Dengan mengambil kira peralihan paradigma dalam pengurusan hutan daripada berorientasikan pengeluaran kayu kepada berasaskan pengurusan sumberdaya, kekuatan untuk menggunakan perkhidmatan alam sekitar mesti selaras secara praktikal dan dengan itu perdagangan karbon akan membentuk satu potensi yang berdaya saing. Untuk mencapai matlamat ini, kita perlu bersedia untuk memulihara dan menguruskan sumber-sumber hutan yang masih ada secara berterusan dan menjalankan program-program penanaman semula hutan di kawasan-kawasan yang rosak.

Dalam pengurusan sumber hutan secara mampan, untuk mencapai SFM memerlukan amalan pembalakan yang bertanggungjawab terhadap alam sekitar. Dengan itu minat yang semakin mendalam dalam pengurangan kesan pembalakan (RIL) sebagai satu strategi alternatif untuk menggalakkan amalan perhutanan yang baik di kawasan tropika dijangka boleh terus dan memenuhi fungsi ekosistem hutan. Banyak kajian menunjukkan bahawa pengurangan kesan teknik pembalakan (RIL) dapat mengurangkan kerosakan kepada pokok-pokok di dirian tinggal dan mengurangkan jumlah kawasan tanah diganggu oleh jentera. Walau bagaimanapun, data dan maklumat mengenai ciri-ciri hutan yang telah dibalak dan kesesuaian teknik

RIL dalam hutan tropika adalah kurang. Atas sebab-sebab ini, kajian mengenai keberkesanan RIL di peringkat operasi dan kesannya terhadap sisa dirian hutan perlu dinilai berdasarkan tahap kerosakan, kawasan terdedah dan potensi pengeluaran sisa dirian hutan yang dikaitkan dengan hasil mampan (kajian 1).

Kajian keberkesanan teknik RIL dalam hutan semulajadi telah dijalankan di beberapa buah syarikat konsesi hutan di Borneo, Indonesia, dengan memberi fokus kepada pencirian struktur dan komposisi hutan pada intensiti pembalakan yang berbeza. Inventori hutan untuk kedua-dua inventori sebelum dituai dan selepas dituai telah dijalankan di kawasan 100 hektar untuk setiap intensiti pembalakan yang berbeza yang ditentukan berdasarkan diameter had dituai, iaitu 40 cm, 50 cm dan gabungan 40 cm dan 50 cm. Inventori pra-musim menuai telah dijalankan untuk semua kategori pokok (garis pusat 20 cm ke atas), kemudian pemetaan pokok, perancangan jalan dan lorong penarik, dan menentukan tebangan berarah dilaksanakan. Selepas penuaian, inventori lepas tuai telah dijalankan untuk mengira tahap kerosakan dan kawasan pendedahan. Sisa pokok tinggal dan pokok rosak dikira dan digunakan untuk menilai keberkesanan teknik RIL pada intensiti pembalakan yang berbeza. Pembalakan dengan had diameter pokok 50 cm menghasilkan keadaan tegakan sisa yang lebih baik dari segi bilangan dan isipadu, mesra alam sekitar dengan tahap yang rosak dan kawasan pendedahan yang lebih rendah berbanding dengan intensiti yang lebih tinggi dengan pembalakan dengan had diameter pokok 40 cm dan gabungan 40 dan 50 cm. Sisa dirian dapat dipulihkan pada usia 35 tahun di bawah had D 40 cm dalam hutan primer, manakala pembalakan dijalankan pada hutan sekunder 22 tahun selepas dibalak tidak dapat dipulihkan, maka sisa pokok-pokok tinggalan perlu putaran panjang 57.3 – 63.2 tahun untuk mencapai hasil yang mampan.

Oleh kerana intensiti pembalakan amat mempengaruhi keberkesanan RIL dan kepadatan sisa dirian pokok, ia secara langsung akan mempengaruhi potensi pengeluaran, maka nombor, penentuan had diameter, taburan dan keadaan silara pokok tuaian dan peraturan pemotongan kitaran (umur giliran) perlu dipertimbangkan. Penyeliaan dan pemantauan dari kerajaan juga perlu dilakukan semasa operasi pembalakan untuk memastikan bahawa teknik RIL dijalankan pada prosedur yang betul, dan dengan itu memenuhi fungsi ekologi dan ekonomi ekosistem hutan.

Dalam bidang pembalakan, adalah penting untuk menggunakan sistem penuaian yang sesuai yang mematuhi prinsip-prinsip SFM, dan dalam menjalankan program penanaman semula hutan yang rosak, mencapai SFM memerlukan teknik silvikultur yang sesuai melalui pemulihbaikan hutan atau campur tangan, seperti rehabilitasi dan restorasi. Secara amnya, bagaimanapun, rawatan silvikultur yang sesuai di peringkat tapak semaian dan juga di peringkat operasi adalah terhad dan spesifik kepada tapak tertentu. Kekurangan data lapangan tersebut telah menjadi halangan untuk menjalankan penilaian keberkesanan rawatan silvikultur pada perubahan produktiviti di hutan yang telah rosak.

Program penanaman semula hutan melalui pengenalan semula spesies pokok yang hilang, terutama dipterokap yang tumbuh pesat dilaksanakan untuk menyekat tanah rosak, maka kajian ini memberi tumpuan kepada *Shorea leprosula* sebagai spesies yang berdaya saing untuk digunakan bagi program penanaman semula hutan dan menawarkan peluang-peluang untuk meningkatkan penyerapan karbon. *Shorea leprosula* juga merupakan keluarga dipterokap yang membentuk sebahagian besar hutan tropika di Asia Tenggara yang telah dibalak secara komersil selama bertahun-tahun, dan telah mengalami pengurangan populasi secara besar-besaran terutamanya kerana kadar eksploitasi perkayuan yang tinggi.

Mengembalikan hutan rosak yang ditunjukkan oleh kesuburan tanah dan bahan organik rendah kerana kitaran nutrien tidak seimbang adalah amat penting. Bahan organik telah dikenal pasti sebagai elemen penting dalam banyak ciri-ciri tanah dan prosesnya, dan penting untuk produktiviti, struktur dan kesuburan tanah dalam ekosistem daratan. Walau bagaimanapun, pengaruh bahan organik pada tanah bergantung kepada bilangan, jenis dan saiz bahan organik.

Kajian atas aplikasi bahan organik telah dijalankan di peringkat tapak semaian (kajian 2) untuk menilai jenis dan kadar penggunaan bahan-bahan organik yang berbeza ke atas pertumbuhan dan pengumpulan biojisim dan untuk menentukan applikasi yang sesuai untuk restorasi hutan di kawasan tropika lembap di Semenanjung Malaysia. Tanah mineral dari tanah terosot telah dipinda dengan kadar bahan-bahan organik yang berbeza, seperti sludge, kompos, mesokarpa kelapa sawit dan kombinasinya dan kadar aplikasi adalah 0, ⅓, ½, ⅔, dan ¾ daripada v/v. Pengukuran pertumbuhan telah dijalankan pada setiap bulan untuk tumbesaran awal sehingga 3 bulan selepas aplikasi dan berterusan bagi setiap tiga bulan, manakala biojisim diukur pada permulaan, 3, 6- dan 12 bulan selepas aplikasi dengan kaedah pensampelan secara destruktif. Pertumbuhan anak pokok dan pengumpulan biojisim bertambah pada semua pindaan, tetapi aplikasi sludge dengan kadar 67% dan lebih akan meningkatkan kadar kematian. Kadar pertumbuhan *Shorea leprosula* meningkat dengan penurunan kadar penggunaan campuran bahan-bahan organik. Berdasarkan kajian ini, program restorasi pada hutan tropika terosot tanpa menggunakan bahan organik menunjukkan kadar pertumbuhan dan pengumpulan biojisim yang rendah, maka aplikasi bahan organik menjadi salah satu keperluan rawatan yang diperlukan untuk keputusan yang lebih baik. Kompos serta jenis struktur tanah hutan sebelumnya merupakan faktor penting yang menyebabkan pertumbuhan yang terbaik dengan kadar kemandirian yang tinggi dan disyorkan untuk teknik restorasi di Hutan Simpan Tekai, Pahang, Malaysia dan kawasan perbandingan lain. Kajian ini mencadangkan bahawa untuk program restorasi berjaya, kajian awal di peringkat tapak semaian perlu dilakukan sejak awal untuk membantu memulihkan ekosistem yang rosak, gagal, atau musnah.

Rehabilitasi hutan melalui penubuhan hutan ladang berfungsi untuk mengasingkan karbon dalam jumlah besar dan dipertimbangkan sebagai salah satu pilihan sektor perhutanan untuk mengurangkan harga kayu yang semakin meningkat dan juga untuk mengurangkan tekanan ke atas baki

hutan semulajadi. Walaupun hutan ladang mempunyai potensi produktiviti yang tinggi, ia mungkin mempunyai hasil yang rendah dan menyebabkan pemerosotan tanah jika diuruskan dengan tidak baik. Walau bagaimanapun, data dan maklumat mengenai faktor-faktor yang mengawal produktiviti hutan ladang dan mengenai cara-cara untuk menguruskan tanah untuk mengekalkan produktiviti tanaman pokok adalah tidak mencukupi. Oleh itu, kajian ke atas rekabentuk penanaman dalam rehabilitasi hutan (kajian 3) dan sistem penanaman (kajian 4) kepada produktiviti dan pengumpulan biojisim telah dinilai untuk memenuhi permintaan masa depan penggunaan kayu dan untuk membanteras pemanasan global.

Pengurusan hutan multi-jenis (MSFM) adalah teknik rehabilitasi yang berdaya saing untuk menggalakkan pembangunan dan pengurusan hutan di kawasan tropika. MSFM ditubuhkan di Hutan Simpan Chikus, Perak pada tahun 1992 untuk merubah hutan miskin kepada hutan ladang untuk memenuhi permintaan masa depan penggunaan kayu dan untuk membanteras pemanasan global. Plot eksperimen telah ditubuhkan untuk menunjukkan lima rekabentuk penanaman yang berbeza, iaitu jenis A; satu deretan ditanam spesies kayu jenis asli berkualiti tinggi (*Shorea leprosula*) dan satu baris pokok eksotik yang dikekalkan pada umur 3 tahun (*Acacia mangium*), 1: 1, Jenis B; 2: 2, Jenis C; 4: 4, jenis D; 8: 8 dan jenis E; 16:16 dalam dua arah penanaman yang berbeza iaitu utara ke selatan dan barat ke timur. Setiap plot mempunyai keluasan kira-kira satu hektar dengan jarak tanam 3.0 m x 3.7 m. Arah barisan tanaman tidak berbeza antara satu sama lain bagi kedua-dua kadar pertumbuhan dan kemandirian. Dalam pertumbuhan awal sehingga umur 8 tahun, pertumbuhan diameter dan ketinggian cenderung meningkat dengan beberapa baris dari jenis A hingga jenis E, kecuali ketinggian pokok jenis E, akibat persaingan antara jenis yang rendah. Pada usia 16 tahun, *S. leprosula* hampir dominan dalam semua rekabentuk penanaman hutan pelbagai jenis dan dapat menggantikan spesies eksotik *A. mangium*. Persaingan untuk kedua-dua antara jenis dan dalam jenis adalah tinggi seperti yang digambarkan oleh kadar kemandirian yang menurun dengan peningkatan jumlah baris berturut-turut dari jenis B hingga jenis E, begitu juga dengan kenaikan tahunan. Prestasi terbaik pertumbuhan pokok adalah jenis C, iaitu empat baris *S. leprosula* dan empat baris *A. mangium* dengan 21.99 cm, 20.09 m dan 66.4% daripada diameter purata, ketinggian dan kadar kemandirian masing-masing. Jumlah isipadu pada rekabentuk penanaman terbaik adalah 152.23 m^3 ha^{-1} dan jumlah biojisim adalah 79.42 t ha^{-1} (≈ 34.76 t C bersih ha-1), 59.62 t ha-1 daripada biojisim atas tanah dan 19.80 t ha^{-1} daripada biojisim akar. Rekabentuk penanaman terbaik boleh menyerap 124.97 t CO_2 bersih. Rekabentuk penanaman jenis C adalah disyorkan untuk prestasi pertumbuhan optimum, produktiviti dan kapasiti penyerapan CO_2 dalam pengurusan hutan. Kajian ini juga menghasilkan persamaan spesifik (*tier* 3) dan kandungan karbon pada komponen pokok yang berlainan dan umur pokok melalui kaedah persampelan destruktif. Bahagian biojisim adalah 56.88, 14.92, 3.48, dan 24.85% bagi batang, dahan, daun dan akar, manakala kandungan purata karbon ialah masing-masing 43.77, 42.63, 43.55 dan 41.02%.

Shorea leprosula atau dipanggil meranti merah adalah sesuai untuk menjadi salah satu spesies berdaya saing untuk penanaman semula hutan dan juga untuk menggantikan spesies eksotik, bagaimanapun, spesies ini mempunyai corak berbunga tidak teratur dan tempoh penyimpanan benih yang pendek. Oleh itu, pembiakan tampang menawarkan penyelesaian yang boleh dilaksanakan untuk pengeluaran anak benih. Data mengenai pencapaian pembiakan tampang dalam bidang ini sangat terhad dan ini perlu diuji sebelum disyorkan untuk penubuhan ladang berskala besar. Khususnya, tiada kajian biojisim telah diljalankan ke atas pokok dari keratan batang.

Penilaian potensi pengeluaran dan pengumpulan biojisim *S. leprosula* pada umur 12 tahun daripada keratan batang telah dijalankan di tapak penyelidikan Gunung Dahu, Jawa Barat, Indonesia. Berdasarkan taburan *basal area*, sebanyak 18 sampel yang mewakili jarak penanaman dan jenis yang berlainan juga telah dilakukan melalui teknik destruktif. Hasil kajian menunjukkan bahawa diameter dan ketinggian pertumbuhan dan bahagian silara didapati mempunyai hubungan positif dengan jarak rejim kecuali kadar kemandirian yang didapati mempunyai hubungan negatif. Prestasi pertumbuhan spesies yang ditanam dalam sistem monokultur menunjukkan hasil yang lebih baik daripada yang lain ditanam dalam sistem campuran dengan *Pinus* untuk semua rejim jarak, manakala bahagian silara tidak berbeza antara satu sama lain. Model regresi yang berkaitan dengan parameter pertumbuhan, seperti diameter (D) dan ketinggian (H) untuk menghitung jumlah dan biojisim komponen pokok atau gabungan komponen pokok telah dibina. Model-model ini kemudiannya digunakan untuk menganggarkan isipadu batang dan pengumpulan biojisim untuk semua tapak. Potensi pengeluaran *S. leprosula* pada umur 12 tahun dari isipadu batang adalah masing-masing pada 154.85, 136.97, 38.95 dan 83.22, 72.99, 48.41 m^3 ha dalam sistem monokultur yang ditanam dengan jarak tanaman 2 x 2, 3 x 3, 5 x 5 dan sistem campuran dengan *Pinus* pada jarak tanaman 2 x 2, 3 x 3 dan 5 x 5 m dan jumlah pengumpulan biojisim adalah 89.89, 76.78, 24.27 dan 49.74, 43.95, 30.05 t ha^{-1}.

Berdasarkan kajian 4, individu pokok bertindak balas kepada jarak yang lebih luas dan persaingan yang lebih rendah menghasilkan pengeluaran individu dan pengumpulan biojisim serta pertumbuhan diameter yang lebih baik, dengan sistem penanaman monokultur cenderung lebih tinggi dalam produktiviti daripada sistem penanaman campuran. Berdasarkan angka bagi potensi pengeluaran dan pengumpulan biojisim menunjukkan bahawa kuantifikasi mereka boleh dianggarkan dengan hanya menggunakan D atau gabungan DH untuk persamaan spesifik tapak dan semua tapak.

Sejak produktiviti hutan dipengaruhi oleh spesis yang sesuai dengan keadaan tapak dan teknik penanaman, maka jarak, jenis tanaman, rekabentuk penanaman dan penggunaan bahan-bahan organik perlu dipertimbangkan untuk memastikan kemampanan dalam menghasilkan produktiviti yang tinggi dan untuk rehabilitasi dan restorasi hutan di masa depan.

Berdasarkan kajian 1 hingga 4, data inventori hutan cenderung bervariasi, terutamanya dalam mozek landskap yang sangat beragam, di hutan yang

berlainan jenis dan rawatan silvikultur yang berbeza. Kajian ini telah menunjukkan bahawa hubungan alometrik umum yang diuji tidak setepat dengan persamaan alometrik yang spesifik. Oleh itu, dengan menukar data inventori hutan kepada isipadu, biojisim dan karbon hutan dipterokarp di Asia Tenggara, memerlukan pembangunan hubungan alometrik yang spesifik (kajian 5). Untuk tujuan ini, data telah dikumpulkan daripada beberapa tapak di Asia Tenggara, dari kedua-dua hutan ladang dan hutan semulajadi. Pokok sampel dari hutan ladang dengan garis pusat lebih kecil daripada 30 cm dipilih berdasarkan taburan diameter, manakala pokok sampel dari hutan semulajadi yang lebih besar daripada 20 cm garis pusat dipilih bergantung kepada struktur pokok normal semasa aktiviti operasi penebangan oleh syarikat-syarikat pembalakan. Secara keseluruhan, 119 sampel pokok dengan D yang terdiri daripada 1.2 cm kepada 114.6 cm dan H yang terdiri daripada 1.9 m hingga 59.1 m telah ditebang. Pemeriksaan ulang pada model persamaan hutan spesifik (model A) menunjukkan bahawa menggunakan D sahaja sebagai peramal pembolehubah telah menghasilkan hubungan yang stabil, tetapi kemasukan H sebagai peramal pembolehubah kedua dapat meningkatkan prestasi model, kedua-dua untuk isipadu batang dan biojisim. Faktor ekspansi biojisim telah menurun dengan peningkatan D daripada 1.6 untuk D kurang daripada 10 cm kepada 1.2 untuk D lebih daripada 40 cm. Kajian ini telahpun dibandingkan dengan beberapa persamaan alometrik yang umum digunakan dan hasilnya menunjukkan bahawa persamaan umum tidak setepat persamaan spesifik untuk menganggar biojisim dalam hutan dipterokap di Asia Tenggara. Persamaan alometrik spesifik adalah disyorkan untuk digunakan dalam anggaran isipadu batang dan jumlah biojisim daripada pengukuran data inventori. Oleh itu, dengan menggunakan persamaan ini, berapa banyak perlepasan gas boleh dikurangkan daripada projek REDD dan / atau berapa banyak CO_2 boleh diserap daripada projek A/R dan IFM boleh dianggarkan dengan lebih tepat dan disahkan.

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I certify that a Thesis Examination Committee has met on 26 June 2014 to conduct the final examination of Ika Heriansyah on his thesis entitled "Evaluation of sustainable forest management techniques for biomass production and carbon sequestration" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Kamziah bt Abd Kudus, PhD
Associate Professor
Faculty of Forestry
Iniversiti Putra Malaysia
(Chairman)

Arifin Abdu, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Mohamad Azani Alias, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Internal Examiner)

Akira Osawa, PhD
Professor
Kyoto University
Japan
(External Examiner)

NORITAH OMAR, PhD
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 18 August 2014

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Hazandy Abd Hamid, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Chairman)

Ahmad Ainuddin Nuruddin, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Shamsudin Ibrahim, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Signature: _____	Signature: _____
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TABLE OF CONTENTS

		Page
ABSTRACT		i
ABSTRAK		vi
ACKNOWLEDGEMENTS		xii
APPROVAL		xiii
DECLARATION		xv
LIST OF TABLES		xix
LIST OF FIGURES		xx
LIST OF ABBREVIATIONS		xxii
CHAPTER		
1	**INTRODUCTION**	1
	1.1 General Background	1
	1.2 Objectives of Study	2
	1.3 Hypothesis	2
2	**LITERATURE REVIEW**	3
	2.1 Deforestation and Forest Degradation	3
	2.2 Strategies to reduce deforestation and forest degradation	8
	2.3 Sustainable forest management in tropical forests	10
	2.4 Forest carbon strategies in climete change mitigation	16
	2.5 Carbon accounting	20
	2.6 Background of Species Selection: *Shorea leprosula*	21
3	**ASSESSMENT OF REDUCED IMPACT LOGGING AT DIFFERENT LOGGING INTENSITY**	22
	3.1 Introduction	22
	3.2 Materials and Methods	23
	3.3 Results and Discussion	25
	3.4 Conclusion	30
4	**MEASURING THE SHORT-TERM SUCCESS OF DIPTEROCARP FOREST RESTORATION: THE USE OF ORGANIC MATERIALS**	32
	3.1 Introduction	32
	3.2 Materials and Methods	34
	3.3 Results and Discussion	35
	3.4 Conclusion	45
5	**THE IMPACT OF MULTI-STORIED FOREST REHABILITATION ON FOREST PRODUCTIVITY AND CARBON SEQUESTRATION**	47
	3.1 Introduction	47
	3.2 Materials and Methods	48
	3.3 Results and Discussion	51
	3.4 Conclusion	56

6 **GROWTH PERFORMANCE, PRODUCTION POTENTIAL AND BIOMASS ACCUMULATION OF 12-YR-OLD *Shorea leprosula* FROM STEM CUTTINGS IN DIFFERENT SILVICULTURE TREATMENTS: CASE STUDY IN WEST JAVA, INDONESIA** 58
3.1 Introduction 58
3.2 Materials and Methods 59
3.3 Results and Discussion 61
3.4 Conclusion 65

7 **ALLOMETRIC EQUATIONS FOR ESTIMATING DIPTEROCARP FOREST BIOMASS IN THE TROPICS OF SOUTHEAST ASIA** 66
3.1 Introduction 66
3.2 Materials and Methods 67
3.3 Results and Discussion 71
3.4 Conclusion 83

8 **SUMMARY AND GENERAL CONCLUSION** 88

REFERENCES 94
BIODATA OF STUDENT 106
LIST OF PUBLICATIONS 107