THE ESTABLISHMENT, SURVIVAL, AND GROWTH OF DIPTEROCARP SEEDLINGS WITHIN LOWLAND DIPTEROCARP FOREST, SABAH, MALAYSIA

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DECLARATION

I hereby declare that the material in this thesis is my own efforts except for quotations, excerpts, equations, summaries and references, which have been fully acknowledged.

17 January 2023

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CERTIFICATION

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ABSTRACT

Tropical forests loss is unprecedented. Efforts had been taken to restore forest loss worldwide, however, the loss is faster than the recovery. The objectives of this study is to 1) estimate the potential of natural regeneration in remnant forests using aboveground carbon density as a surrogate of forest quality, 2) examine biotic and abiotic factors affecting survival and growth of seedlings following a masting event and gain insight into how this contributes to the recovery process. To address the first objective, a total of 446 circular plots were established at seven sites across Sabah. Line transects were used at 5 of the sites, with the other two sites sampled using a cluster plot sampling design. Circular plots measuring 2 m radius were established and the coordinates were marked using Garmin GPSMAP® 64s along the transect line with a minimum of 75 m between each plot. All dipterocarp seedlings within the plots were enumerated. The plot coordinates were overlaid over the Carnegie's Airborne Observatory 30 m resolution carbon map in QGIS and the average aboveground carbon (ACD) determined by averaging the 9 pixel cells surrounding the seedling plot. A generalized linear mixed effect was used to investigate the relationship between ACD and dipterocarp seedling density. For the second objective, eight 16 ha plots were established within Sungai Tiagau Forest Reserve and all trees greater than 25 cm dbh enumerated. Thirty six 2 m radius circular plots were established within each of the 16 ha plots, and all seedlings enumerated. The seedlings were censused four times at irregular interval over a 37 month period and the growth and survival of the seedlings recorded. Kaplan-Meier analysis was used to compare the survival of seedling for community and the 11 most abundant species while generalized linear mixed effects model was used to analyze the effect of biotic and abiotic factors on seedling survival. The biotic factors includes seedling initial height, conspecific and heterospecific seedling and adult tree basal area and seedling diversity while abiotic factors includes canopy openness and organic litter layer thickness. Five models were fitted to the data using different combinations of the explanatory variables including height model, abiotic factor model, conspecific model, interaction of abiotic and conspecific model, and lastly the full model. Relative growth rates of 5 most abundant species were calculated. Factors affecting the RGRs were then analyzed using generalized linear models and the same

biotic and abiotic factors from the survival study. There was a significant relationship between the density of the dipterocarp seedlings and ACD (z = 4.120, p<0.05). Natural regeneration is suppressed below 125 Mg C ha^{-1}, with ACD lower than 40 Mg C ha^{-1} having no seedling. Seedling survival decreased rapidly in the first 2 censuses. *Shorea pauciflora* seedlings had the highest survival (75%) after 37 months and *Shorea parvifolia* the lowest (27%). The initial seedling height significantly affected seedling survival for all species, with taller seedlings having a higher probability of survival. Conspecific seedling and adult tree basal areas only affect *Shorea fallax* survival. *Parashorea smythiesii* had the highest relative growth rates, almost twice that of *Dryobalanops lanceolata,* 0.00051 cm cm^{-1} day^{-1} and 0.00026 cm cm^{-1} day^{-1} respectively. Initial seedling height significantly affected RGR, with taller seedlings having slower RGRs for all studied species. Canopy openness significantly affected all species except *Parashorea smythiesii.* This study demonstrates that natural regeneration occurred only at sites above 125 Mg C ha^{-1} whereas sites below this have to go through either assisted natural regeneration or active restoration. The survival and growth of seedling were highly affected by seedling initial height. This study suggests the use of ACD for forest restoration prescription to increase the effectiveness of forest restoration.

ABSTRAK

PERCAMBAHAN, JANGKA HIDUP, DAN KADAR PERTUMBUHAN ANAK BENIH DIPTEROCARP DALAM HUTAN TANAH RENDAH DIPTEROCARP, SABAH MALAYSIA

Kejadian kemusnahan hutan tropika tidak dapat dikembalikan. Usaha telah diambil untuk mengembalikan kemusnahan hutan di seluruh dunia, malangnya kadar kemusnahan hutan adalah lebih tinggi daripada kadar pemulihan. Projek ini bertujuan untuk 1) menyiasat potensi penjanaan semula semulajadi di hutan yang mengalami kemusnahan dengan menggunakan ketumpatan karbon bahagian atas tanah sebagai kualiti hutan, 2) mengkaji faktor-faktor yang mempengaruhi kemandirian dan pertumbuhan anak benih berurutan peristiwa 'masting' dan mendapatkan gambaran tentang bagaimana ini menyumbang kepada proses pemulihan. Untuk menangani matlamat pertama, sejumlah 446 plot pekeliling telah diwujudkan di tujuh tapak di seluruh Sabah. Kaedah transek lurus digunakan di lima tapak, dengan dua tapak yang lain disampel menggunakan reka bentuk persampelan plot kelompok. Transek mengikuti denai atau ciri topografi sedia ada, plot jejari 2 m telah ditubuhkan di sepanjang garisan transek dengan jarak minimum 75 m antara setiap plot. Semua anak benih dipterocarp di dalam plot telah dikira. Kedudukan semua plot ditentukan menggunakan Garmin GPSMAP® 64s. Koordinat plot ditindih di atas peta karbon Carnegie's Airborne Observatory di QGIS dan purata karbon di atas tanah (ACD) ditentukan dengan purata 9 sel piksel yang mengelilingi plot anak benih. "Generealized linear mixed effect" telah digunakan untuk menyiasat hubungan antara ACD dan kepadatan anak benih dipterocarp. Bagi tujuan kedua, lapan petak seluas 16 hektar telah diwujudkan di dalam Hutan Simpan Sungai Tiagau dan semua pokok melebihi 25 sm dbh dikira. Tiga puluh enam plot bulatan radius 2 m telah diwujudkan dalam setiap plot seluas 16 ha, dan semua anak benih dikira. Anak benih dibanci sebanyak empat kali dalam tempoh 37 bulan dan pertumbuhan dan kemandirian anak benih direkodkan. "Kaplan-Meier Survival Analysis" digunakan untuk membandingkan kemandirian anak benih untuk komuniti dan 11 spesies yang paling banyak manakala "generalized linear mixed effect" digunakan untuk menganalisis kesan faktor biotik dan abiotik terhadap kemandirian anak benih. Kesan

biotik termasuk ketinggian anak benih, anak benih konspesifik dan heterospesifik dan kawasan "basal" pokok dewasa dan kepelbagaian anak benih manakala faktor abiotik termasuk keterbukaan kanopi dan ketebalan lapisan organik. Lima model telah digunakan menggunakan kombinasi berbeza pembolehubah penjelasan termasuk model ketinggian, model faktor abiotik, model konspesifik, interaksi model abiotik dan konspesifik, dan model penuh. Kadar pertumbuhan relatif 5 spesies yang paling banyak telah dikira. Faktor-faktor yang mempengaruhi RGR kemudiannya dianalisis menggunakan "linear model" dan faktor biotik dan abiotik yang sama daripada kajian kebolehhidupan. Terdapat hubungan yang signifikan antara ketumpatan anak benih dipterocarp dengan ACD ($z = 4.120$, $p<0.05$). Parashorea smythiesii mempunyai kadar pertumbuhan relatif tertinggi, hampir dua kali ganda berbanding Dryobalanops lanceolata, masing-masing 0.00051 cm cm-1 hari-1 dan 0.00026 cm cm-1 hari-1. Ketinggian anak benih awal mempengaruhi RGR dengan ketara, dengan anak benih yang lebih tinggi mempunyai RGR yang lebih perlahan untuk semua spesies yang dikaji. Keterbukaan kanopi memberi kesan ketara kepada semua spesies kecuali Parashorea smythiesii. Kajian ini menunjukkan bahawa penjanaan semula jadi hanya berlaku di tapak di atas 125 Mg C ha-1 manakala tapak di bawah nilai ini perlu melalui sama ada penjanaan semula semulajadi yang dibantu atau pemulihan aktif. Kemandirian dan pertumbuhan anak benih sangat dipengaruhi oleh ketinggian awal anak benih. Kajian ini mencadangkan penggunaan ACD untuk preskripsi pemulihan hutan untuk meningkatkan keberkesanan pemulihan hutan.

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ACD	-	Aboveground carbon density
AIC	-	Akaike's Information Criterion
ANOVA	-	Analysis of Variance
GLMM	-	Generalized linear mixed effect model
DBH	-	Diameter at breast height
ENSO	-	El Niño Southern Oscillation
JC hypothesis	-	Janzen-Connell hypothesis
LiDAR	-	Airborne light detection and ranging
LNT	-	Low night-time temperature
Mg C ha^{-1}	-	Megagram of carbon per hectare
Mha	-	Million hectares
NDD	-	Negative density dependence
STFR	-	Sungai Tiagau Forest Reserve
RGRs	-	Relative growth rates

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