Institute of Biodiversity and Environmental Conservation

Advance Reforestation Strategies: Predicting Potential Species from Available Species in Jagoi Heritage Forest (JHF) and Mycorrhizal Fungi-*Trichoderma*-Fertilizer Combined Effects on *Durio zibethinus* and *Artocarpus heterophyllus* Growth

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Doctor of Philosophy
2024

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A thesis submitted

In fulfillment of the requirements for the degree of Doctor of Philosophy

(Environmental Conservation)

Institute of Biodiversity and Environmental Conservation

UNIVERSITI MALAYSIA SARAWAK

2024

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : 26 JULY 2024

ACKNOWLEDGEMENT

I would like to express my deepest gratitude and appreciation to all the people who have guided and helped me in completing this thesis.

First of all, I would like to express my heartfelt gratitude to my supervisors, Professor Dr Gabriel Tonga Noweg and Professor Dr Ismail Jusoh, for their guidance, care and patience during the time spent completing this thesis. They are the main pillars behind this thesis. I would be lost and helpless without them.

Secondly, I would like to thank the Institute of Biodiversity and Environmental Conservation (IBEC) and the Centre for Graduate Studies, for the advice and support given during my period of study at Universiti Malaysia Sarawak. I would also like to thank the management of the Universiti Malaysia Sarawak for making it possible for me to complete my study here in my hometown, Sarawak. The warm and excellent atmosphere provided by them has made my journey less stressful.

I also would like to thank both of my parents and my family members. They are always there for me, endlessly supporting and encouraging me with their warm words. I guess, blood is sure thicker than water.

Last but not least, I would like to thank Stephanie Judi, Vivian Patrick, Bridgette Philip, Olga Ingan, Bobo Teo Sieu Zhien, Pang Sing Tyan, Felicity Tata, Jothyka Sebastian, Johannes Sebastion, Felicia Tata, Francis Tata, and Nana for their supports, helps, warm encouragements and criticisms during this journey. Special thanks also to those who have helped me during my fieldwork including my strong field guides (the late Uncle Ginot Tasan or Pak Jiping, Uncle Sabet Rigong and Uncle Juis Migan), IBEC's lab assistant (Mr Mohd Hasri Al-Hafiz bin Haba and Ms Rahah binti Mohd. Yakub), Jagoi Area Development Committee (JADC) and many more. The hard work on the field cost more than half of this thesis, and it was accomplished all thanks to you.

The journey towards PhD has been long and tiresome yet an eventful moment for me. I would not be able to finish it without all of you. No words can express my gratitude. Thank you all.

ABSTRACT

Reforestation can occur by two main methods namely, natural regeneration and intervention during replanting. This study consists of two experiments. Experiment 1 predicted the potential native tree species for mixed-planting reforestation in degraded areas around Bau District using the ecological criteria using the ecological criteria i.e., natural regeneration status, importance value (IV), and standing biomass (SB). The study was carried out at Jagoi Heritage Forest (JHF), Bau, Sarawak. A total of 52 (20 m x 20 m) nested quadrats were placed systematically in primary forest (PF), old secondary forest (OSF), young secondary forest (YSF), and agroforest (AF). Shannon-Wiener diversity index results showed that YSF and AF have the highest species diversity (H' = 4.10). Kruskal-Wallis H test showed that there is a significant difference in IV ($X^2[3] = 12.20$, p = 0.01) and SB ($X^2 [3] = 27.29$, $p < 0.05$) between forest types. The cross-matched between Indicator species analysis (ISA) result and natural regeneration status found that *Dipterocarpus* sp. and *Archidendron jiringa* (Jack) Nielsen have the highest indicator values (based on IV and SB) and good regeneration. Thus, *Dipterocarpus* sp. and *A. jiringa* has a higher potential for mixed-planting reforestation in degraded areas around Bau District. Meanwhile, Experiment 2 investigated the effect of mycorrhizal fungi and *Trichoderma* (MF-T) application with different fertilizer types and amounts on *Durio zibethinus* Murray (durian) and *Artocarpus heterophyllus* Lam. (jackfruit) growth. A randomized complete block design was used with ten replicates per species of tree per treatment. Seven treatments were used. The profile diagram shows the highest marginal mean of *D. zibethinus* height was at 100 g organic fertilizer (OF) with MF-T (Mean = 65.52), and *A. heterophyllus* height was at 50 g OF with MF-T (Mean = 113.77). The marginal mean stem diameter also showed that the highest mean of *D. zibethinus* diameter was at 100 g chemical fertilizer (CF) with MF-T (Mean = 7.15). However, the highest marginal mean diameter for *A. heterophyllus* was at 50 g OF with MF-T (Mean = 8.98). The factorial ANOVA result indicated that there was a significant difference between treatments versus species of tree on height ($F [6,154] = 12.44, p < 0.05$) and stem diameter ($F [6,154] = 5.57, p < 0.05$). The Tukey post-hoc analysis showed that treatment of 50 g OF with MF-T is the most suitable treatment for the successful establishment of *D. zibethinus* and *A. heterophyllus*. The study concluded that reforestation can be achieved through two methods namely, natural regeneration and manipulation during replanting. A predictive approach based on the tree's natural regeneration status, IV, and SB can predict successful establishment of the selected species in a new area. The replanting method with co-inoculation of MF-T with OF not only helps in promoting plant growth and recovers the soil's chemical and biological properties but also helps in reducing dependencies on chemical fertilizer.

Keywords: Biodiversity, biomass, mycorrhiza fungi, mixed-planting reforestation, natural regeneration

Strategi Pengembangan Semula Hutan: Meramal Spesis Berpotensi daripada Spesis yang Sedia Ada di Hutan Warisan Jagoi dan Kesan Penggunaan Gabungan Trichoderma-Baja Terhadap Pertumbuhan Durio zibethinus dan Artocarpus heterophyllus

ABSTRAK

Penghutanan semula boleh berlaku melalui dua kaedah utama iaitu, pertumbuhan semula jadi dan manipulasi semasa penanaman semula. Kajian ini mengandungi dua eksperimen. Eksperimen 1 meramalkan spesis yang berpotensi untuk penghutanan semula melalui penanaman campur di kawasan terdegradasi di sekitar daerah Bau dengan menggunakan kriteria-kriteria ekologi i.e., status pertumbuhan semula jadi, nilai kepentingan dirian (KD), dan biomas dirian (BD). Kajian ini telah dijalankan di Hutan Warisan Jagoi (HWJ), Bau, Sarawak. Sejumlah 52 (20 m x 20 m) kuadrat bertindih telah diatur secara sistematik di hutan dara (HD), hutan sekunder tua (HST), hutan sekunder muda (HSM), dan hutan pertanian (HP). Keputusan indeks kepelbagaian Shannon-Wiener menunjukkan bahawa HSM dan HP mempunyai nilai kepelbagaian tertinggi (H' = 4.10). Analisis H Kruskal-Wallis menunjukkan terdapat perbezaan signifikan bagi nilai KD (X^2[3] = 12.20, p = 0.01) dan BD (X^2 [3] = 27.29, $p < 0.05$) di antara empat jenis hutan tersebut. Padanan silang antara keputusan analisis spesis indikator (ASI) dan status pertumbuhan semula jadi mendapati Dipterocarpus sp. dan Archidendron jiringa (Jack) Nielsen mempunyai nilai penunjuk tertinggi (berdasarkan nilai KD dan BD) dan pertumbuhan semula jadi yang baik. Oleh itu, Dipterocarpus sp. dan A. jiringa mempunyai potensi untuk penanaman hutan campuran yang tinggi di kawasan terdegradasi di sekitar daerah Bau. Eksperimen 2 pula menyiasat kesan penggunaan kulat mikoriza dan Trichoderma (KM-T) dengan jenis dan jumlah baja yang berbeza ke atas pertumbuhan Durio zibethinus Murray (durian) dan Artocarpus heterophyllus Lam. (nangka). Reka bentuk blok lengkap rawak telah digunakan *dengan sepuluh replikasi bagi setiap spesis pokok dan rawatan. Tujuh jenis rawatan telah digunakan. Plot profil menunjukkan min marginal tertinggi bagi ketinggian D. zibethinus adalah 100 g baja organik (BO) dengan KM-T (Min = 65.5) manakala A. heterophyllus adalah 50 g BO dengan KM-T (Min = 113.8). Min marginal diameter batang juga menunjukkan bahawa min tertinggi untuk D. zibethinus adalah 100 g baja kimia (BK) dengan KM-T (Min = 7.15). Namun begitu, min marginal tertinggi untuk diameter batang A. heterophyllus adalah 50 g BO dengan KM-T (Min = 8.98). Keputusan faktorial ANOVA menunjukkan terdapat perbezaan signifikan di antara rawatan melawan spesis pokok terhadap ketinggian (*$F_{[6,154]} = 12.44$, $p < 0.05$*) dan diameter batang (*$F_{[6,154]} = 5.57$, $p < 0.05$*). Analisis post-hoc Tukey menunjukkan bahawa rawatan 50 g OF dengan KM-T adalah rawatan yang paling sesuai untuk pertumbuhan D. zibethinus dan A. heterophyllus. Kajian ini menyimpulkan bahawa penghutanan semula boleh dicapai melalui dua kaedah iaitu, pertumbuhan semula jadi dan manipulasi semasa penanaman semula. Kaedah ramalan berdasarkan status pertumbuhan semula jadi, nilai KD, dan BD dapat meramalkan kejayaan pertumbuhan spesis terpilih di kawasan baharu. Kaedah penanaman semula dengan inokulasi bersama KM-T dengan BO bukan sahaja membantu dalam menggalakkan pertumbuhan tumbuhan dan memulihkan kandungan kimia dan biologi tanah, tetapi juga membantu dalam mengurangkan pergantungan kepada baja kimia.*

Kata kunci: *Kepelbagaian biologi, biomas, kulat mikoriza, penghutanan semula melalui penanaman campur, pertumbuhan semula jadi*

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AF	Agroforest
AMF	Arbuscular mycorrhizal fungi
ANOSIM	Analysis of Similarities
ANOVA	Analysis of Variance
ANR	Assisted natural regeneration
BA	Basal area
CBC	Community-based-conservation
CBH	Circumference at Breast Height
CF	Chemical fertilizer
DBH	Diameter at Breast Height
DSH	Diameter at Stump Height
E	Pielou's evenness index
FAO	Food and Agriculture Organization
FRIM	Forest Research Institute Malaysia
GFGP	Grain-for-Green Program
H'	Shannon-Wiener diversity index
ISA	Indicator species analysis
ITTO	International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
IV	Importance Value
IVI	Importance Value Index
JADC	Jagoi Area Development Committee
JHF	Jagoi Heritage Forest

Kg.	*Kampung* (village)
MF-T	Mycorrhizal fungi and *Trichoderma*
N	Nitrogen
OF	Organic fertilizer
OSF	Old secondary forest
P	Phosphorus
PASW	Predictive Analytical Software
PC	Personal computer
PCoA	Principal coordinates analysis
PF	Primary forest
RCBD	Randomized complete block design
S	Menhinick richness index
SFM	Sustainable Forest Management
Sg.	Sungai
SP	South Pole
SSB	Seedling/sapling standing biomass
TSB	Tree’s standing biomass
UNDP	United Nation Development Programme
UNEP-WCMC	United Nation Environment Programme World Conservation Monitoring Centre
UPM	Universiti Putra Malaysia
YSF	Young secondary forest

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Forest and humans have an interchangeable relationship in which, both play crucial roles to ensure the continuity of one another. Forest has multiple functions, including as a gene pool, carbon sink, source of timber and non-wood forest products, provides multiple ecosystem services, and a home for wildlife and indigenous people (Chazdon et al., 2016). However, this relationship has constantly been abused by humans, and this has put the forest in a critical condition. Hence, an effort to rehabilitate the forest has been widely discussed and practised. One of the possible solutions is reforestation. The reforestation initiative has proven to conserve and rehabilitate the natural forests from further degradation while providing environmental services (Hashim et al., 2015).

The Malaysian reforestation strategy can be divided into two main methods namely, natural regeneration and replanting with native or exotic species (Wan Mohd et al., 2015). In the United States of America, 'reforestation' is defined as transforming non-forested areas into forests through active restoration using the planting method or passive restoration using natural regeneration (Hanson et al., 2015). Reforestation can also be conducted through nucleation, vegetation clustering, and agroforestry methods (Shimamoto et al., 2018). The increasing rate of deforestation in the Southeast Asia region due to agriculture, urbanization, increased demand for timber, and forest fires has led to the adoption of reforestation and forest conservation policies (Ahmadzai et al., 2023). It is expected that through continuous effort of reforestation, the Southeast Asia region will gain 19.6 million ha of forests by 2050 (Estoque et al., 2019).

Malaysia is among the tropical countries, which had recently started reforestation initiatives through forest plantation due to high demand for timber and the depletion of natural forests (Hashim et al., 2015). According to a study by Estoque et al. (2019), Malaysia has lost 16.6% from the total of 80 million ha of forest loss in the Southeast Asia, between 2005 and 2015. Although there have been several forest plantations established to cope with the demand for timber and to reforest the degraded forests, the success rate of reforestation is yet to be determined, and more research is needed to improve the results (Abd Latif et al., 2018). Despite the uncertainty, forest plantations may have the potential to offer social and environmental benefits and would slowly replace the dependency on natural forests (Hashim et al., 2015).

Hence, there is a need for a comprehensive evaluation of the targeted species for reforestation and a new alternative to overcome these concerns. This study covers both methods of reforestation namely, the natural regeneration method and replanting method. It was divided into two experiments in which, the first experiment predicted the potential tree species for mixed-planting reforestation in degraded areas around Bau District using the ecological criteria i.e., natural regeneration status, importance value (IV), and standing biomass (SB). The study has been carried out at Jagoi Heritage Forest (JHF), Bau, Sarawak, in two primary forest (PF), five old secondary forest (OSF), four young secondary forest (YSF), and three agroforest (AF) sites.

The second experiment investigated the potential of mycorrhizal fungi and *Trichoderma* (MF-T) as biofertilizers to accelerate the growth of planted trees in reforestation works. It was carried out in the greenhouse's environment for one year. *Durio zibethinus* and *Artocarpus heterophyllus* were selected, planted, and treated with seven types of treatments, including the control treatment. The treatments involve the fertilization procedure using two types of fertilizer namely, organic (OF) and chemical fertilizer (CF), with inoculation of MF-T.

The results from the first experiment are important to determine the dominant native tree species from JHF that is suitable for planting in reforestation areas around Bau District. The results from the second experiment then provide insight into methods to accelerate reforestation.

Each main topic is divided into two sections namely, (a) Experiment 1: Predicting the Potential Species for Reforestation Based on Natural Regeneration Status, Importance Value and Standing Biomass, and (b) Experiment 2: The Effect of Mycorrhizal Fungi and *Trichoderma* Application with Different Fertilizer Types and Amounts on *Durio zibethinus* and *Artocarpus heterophyllus* Growth.

1.2 Predicting the Potential Species for Reforestation Based on Natural Regeneration Status, Importance Value and Standing Biomass

1.2.1 Background of Study for Experiment 1

Reforestation has been a complicated yet essential effort to combat the challenges of deforestation, climate change, and biodiversity loss (Food and Agriculture Organization [FAO], 2015b). It can contribute to the world's economic growth, poverty alleviation, food security, climate resilience, biodiversity conservation, and the rule of law (Stanturf et al., 2015). Reforestation is made up of multiple elements, among all monitoring and evaluating processes. Monitoring and evaluating is one of the important elements in reforestation as they provide a lot of useful information on the activities conducted, predict the results, and assist the forest management (FAO, 2015b). However, monitoring and evaluating reforestation is a complicated process with heated debates on what qualifies successful reforestation and how best to measure it. The monitoring and evaluation process can be categorized into three aspects, namely, ecological, economic, and social. The ecological aspects are divided into three attributes namely, vegetation structure, diversity and abundance, and ecological processes (Le et al., 2015).

Past reforestation efforts, such as in the degraded area of former copper mining in Sabah often prefer exotic species due to its fast growth rate and environmental-stress tolerance. However, the growth performance of the exotic species planted varied between different species and sites in the same area (Lintangah et al., 2016). Introducing exotic species may also disrupt the natural environmental and ecological process, indirectly leading to high maintenance costs to preserve the natural environment (FAO, 2015b).

Numerous past studies have also been conducted to investigate the ecological attributes of vegetation structure, diversity, and abundance in different forest areas, such as Aliyi et al. (2015) in tropical montane forests, Kuma and Shibru (2015) in dry woodland forests, and Maua et al. (2020) in tropical rainforests. In tropical montane forests, Aliyi et al. (2015) investigate the flora's structure, diversity, and abundance. Their findings showed a wide variety of plant species with significant degrees of endemism and distinctive adaptations to the alpine habitat. The study emphasised how crucial it is to preserve the forests due to their ecological value and capacity to preserve biodiversity. Then, Kuma and Shibru's (2015) discovered that dry woodland forests had less species diversity compared to other forest types. However, they identified several indigenous tree species that demonstrated tolerance to arid conditions, indicating their potential for regeneration and reforestation initiatives in dry areas. The study by Maua et al. (2020) then emphasised the remarkable richness of tropical rainforests, which contain a wide variety of plant species and intricate ecological relationships. Additionally, Maua et al. (2020) discovered possible local species that could be employed in reforestation efforts to restore degraded rainforests. However, these studies indicate the need to systematically identify the potential native species that could be used in reforestation efforts based on their ecological adaptability.

Among the most recent conservation-based research conducted in JHF involving the diversity of vegetation, such as medicinal plants and non-timber forest products are by Ripen and Noweg (2016), Baling et al. (2017), and Toaiang and Sayok (2019). The present research has mainly concentrated on the diversity and utilisation of plants. However, there has been a lack of identification of native species that have the potential for replanting in other degraded areas. Researching local species with quick growth, high environmental adaptation, and ecological significance could help reforestation succeed.

Studies conducted to determine the potential species for reforestation, such as Saha et al. (2016) in Dhanaulti of Garhwal Himalaya, Mallegowda et al. (2018) in South India, and Thang et al. (2018) in northwestern Vietnam also mainly focus on the economic value of the species and single-ecological criterion, rarely combining several ecological criteria. These research findings may have shed important light on the suitability and distinctive traits of different tree species for reforestation in diverse localities. A thorough understanding of the optimal reforestation techniques may be hampered by research gaps caused by the absence of studies combining the traits of several species. The two primary research issues