UNIVERSITI PUTRA MALAYSIA

ECOLOGICAL IMPACT OF Acacia mangium Willd. INVASION IN SECONDARY FORESTS IN PUCHONG, SELANGOR, MALAYSIA

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By

YOUNES H SOLAIMAN SHEIP

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

To the spirit my father: I will do all that I can do for your satisfaction in your grave, thank you for unconditional support with my life, I am honoured to have you as my father, thank you for giving me a chance to prove and improve myself through all my walks of life.

To my beloved wife, wonderful children: thank you for believing in me, for allowing me to further my studies.

To my brothers and sisters: Hoping that with this research I have proven to you that there is no mountain higher as long as God is on our side. Hoping that you will walk again and be able to fulfil your dreams.

To my teachers, instructors and mentors: my sincere thanks for making it a reality, and utmost respect to all my teachers past, present and future, and to all teachers everywhere.

To my friends, I also dedicate this dissertation and give special thanks to my many friends who have supported me throughout this process.

I would like to conclude by again expressing my deepest gratitude and love to all.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor Hazandy Abdul Hamid, PhD
Faculty : Forestry and Environment

Invasive exotic species pose a serious threat to the conservation of native species, communities, and ecosystems. There are various species of economic trees that are exotic to Malaysia and among these commercial trees with invasive properties *Acacia mangium*. It has become increasingly clear that those exotic tree species used in the commercial and agroforestry industry can cause major problems as invaders of natural and semi-natural/disturbed ecosystems as they can become structurally dominant in terrestrial situations. This study aimed to evaluate the distribution of the spatial patterns of the population of Acacia species expanding inside degraded forests of secondary trees in Malaysia, to understand the *Acacia mangium* trees invasion on open sites, degraded secondary forests, and agricultural lands. The study site was divided into four regions starting from the open ground region passing through the acacia trees region, the transitional region that lies between the *A. mangium* region and the native forest region up to the native forest region in the study site. Each region was divided into six plots which were created in the open ground region (OG), the *A. mangium* region (AM), the transition region (TZ), and the native forest region (NF). A total of 24 plots were created wherein each plot was 20 x 20m in size. The study sought to compare the Physico-chemical characteristics of the soils in the four regions. Composite soil samples were obtained from each subplot at 0-15 cm depth (topsoil) and 15-30 cm depth (subsoil) from a randomly selected location within the OG, AM, TZ, and NF region respectively. The abundance, density, and frequency of trees, seedlings, and seedlings were estimated and compared in the studied regions, Quadrat data were used for the computation of analytical features such as density, frequency, and abundance. Wherein the Importance Value Index (IVI) was calculated to express the dominance and success of the biological invasion of any species. Shannon–Weiner index (*H'*), Concentration of dominance (*Cd*), Pielou’s evenness index (*Jsw*), and Margalef’s index of species richness (*Dmg*) were also calculated. Seedlings' and saplings' growth performance were evaluated and compared whereby the studied species were selected from those which grew inside the forest under the canopy of trees (shade) and outside the forest in the gaps and open ground. To determine the growth performance (total height, the diameter of the base, and counting leaves) of seedlings and saplings, they were monitored monthly for six months. The results showed that the Physico-chemical variables in the study site were not significantly different. There was a significant difference ($p \leq 0.05$) in the depth of the organic layer in the native forest region, unlike other regions the GWC in the topsoil was significantly higher compared to the subsoil. However, the Acacia trees region soils showed significantly higher total nitrogen concentration than the rest of other riggings soils. The distribution analysis of the tree species in the invaded region *by A. mangium* indicated the highest values of IVI than the native forest region. In terms of Margalef's index of species richness (*Dmg)*, Pielou's evenness index (*Jsw*), and Shannon's diversity index (*H'*) their highest values were recorded in the native forest region. In contrast, the Simpson index for the concentration of dominance (*Cd*) was higher in the *A. mangium* region. The study revealed that *A. mangium* had high adaptability on degraded secondary forest land. Wherein the growth performance in seedling and sapling of *A. mangium* showed a significant increase ($p < 0.05$) in open ground regions compared with the other species in the native forest region. Therefore, this study concluded that non-native *A. mangium* trees have the ability to alter the soil physicochemical properties to improve their growth. It also showed that the *A. mangium* is a source of continuous dispersal and invasion. Moreover, *A. mangium* also increased at greater density and abundance compared to native trees. *A. mangium* could rapidly become a serious threat to the biodiversity of degraded secondary forest land in close proximity to the Acacia plantation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

KESAN EKOLOGI PENCEROBOHAN *Acacia mangium* Willd. DALAM HUTAN SEKUNDER DI PUCHONG, SELANGOR, MALAYSIA

Oleh

YOUNES H SOLAIMAN SHEIP

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Pengerusi : Profesor Hazandy Abdul Hamid, PhD
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Spesies eksotik dan invasif merupakan salah satu ancaman paling besar terhadap pemuliharaan spesies, komuniti, dan ekosistem asli. Terdapat pelbagai spesies pokok ekonomi yang eksotik di Malaysia, di antara pokok komersil yang bersifat invasif adalah *Akasia mangium*. Adalah semakin jelas bahawa spesies pokok eksotik yang digunakan dalam komersial dan industri agroforestri dapat menyebabkan masalah besar sebagai penyerang semula jadi dan ekosistem separa semula jadi/terganggu kerana ia boleh menjadi struktur darat yang dominan. Kajian ini bertujuan untuk menilai penyebaran corak spasial populasi spesies Akasia yang berkembang di dalam hutan sekunder yang terdegradasi di Malaysia, untuk memahami pencerobohan pokok *Akasia mangium* di kawasan terbuka, hutan sekunder yang terdegradasi dan tanah pertanian. Tapak kajian dibahagikan kepada empat wilayah yang bermula dari wilayah tanah terbuka yang melewati wilayah pohon akasia, wilayah peralihan yang terletak di antara wilayah *A. mangium* dan wilayah hutan asli hingga wilayah hutan asli di kawasan kajian. Setiap wilayah dibahagi kepada enam petak yang didirikan di wilayah tanah terbuka (OG), wilayah *A. mangium* (AM), wilayah peralihan (TZ), dan wilayah hutan asli (NF). Terdapat sejumlah 24 petak di mana setiap petak berukuran 20 x 20m. Kajian ini bertujuan untuk membandingkan ciri-ciri fisik-kimia tanah di empat wilayah tersebut. Sampel komposit diperoleh dari tanah setiap sub-petak pada kedalaman 0-15 cm (tanah atas) dan kedalaman 15-30 cm (tanah bawah tanah) setiap petak, dari lokasi yang dipilih secara rawak dalam setiap wilayah di OG, AM, TZ, dan NF. Kelimpahan, kepadatan, dan frekuensi pokok, dan anak benih dianggarkan dan dibandingkan di antara wilayah yang dikaji. Data Quadrat digunakan untuk pengiraan ciri analitik seperti kepadatan, frekuensi, dan kelimpahan. Di mana Indeks Nilai Kepentingan (IVI) dikira untuk menyatakan dominasi dan kejayaan pencerobohan biologi terhadap mana-mana spesies. Indeks Shannon-Weiner (*H*'), Konsentrasi dominasi (*Cd*), Indeks Keseimbangan Pielou (*Jsw*), dan Indeks Kekayaan Spesies (*Dmg*) Margalef adalah dikira. Prestasi pertumbuhan anak benih dan anak pokok dinilai dan dibandingkan di mana spesies yang dikaji dipilih yang tumbuh di dalam hutan di bawah kanopi pokok (teduhan), di celah-celah hutan dan tanah terbuka. Dalam menentukan prestasi pertumbuhan (jumlah ketinggian, ukuran garis pusat pangkal, dan pengiraan daun) anak benih dan anak pokok dipantau setiap bulan selama enam bulan untuk menilai pertumbuhannya. Hasil kajian menunjukkan bahawa pemboleh ubah fisik-kimia di kawasan kajian tidak berbeza secara signifikan. Terdapat perbezaan yang signifikan ($p \leq 0.05$) pada kedalaman lapisan organik di wilayah hutan asli, tidak seperti wilayah lain, GWC di tanah atas jauh lebih tinggi dibandingkan dengan tanah bawah tanah. Walau bagaimanapun, tanah di wilayah pokok Akasia menunjukkan kepekatan jumlah Nitrogen yang jauh lebih tinggi daripada tanah riggings yang lain. Analisis taburan spesies pokok di wilayah yang diceroboh oleh *A. mangium* menunjukkan nilai IVI tertinggi berbandingan dengan wilayah hutan asli. Nilai tertinggi bagi Indeks Kekayaan Spesies Margalef (*Dmg*), Indeks Keseimbangan Pielou (*Jsw*), dan Indeks Kepelbagaian Shannon (*H'*) dicatatkan di wilayah hutan asli. Sebaliknya, Indeks Simpson untuk Konsentrasi Dominasi (*Cd*) lebih tinggi di wilayah *A. mangium*. Kajian itu menunjukkan bahawa *A. mangium* mempunyai kemampuan menyesuaikan diri yang tinggi di tanah hutan sekunder yang terdegradasi. Di mana prestasi pertumbuhan anak benih dan anak pokok *A. mangium* menunjukkan peningkatan yang signifikan ($p < 0{,}05$) di wilayah tanah terbuka berbanding dengan spesies lain di wilayah hutan asli. Oleh itu, kajian ini menyimpulkan bahawa pokok *A. mangium* yang bukan tumbuhan asal mempunyai keupayaan untuk mengubah sifat fizik-kimia tanah untuk meningkatkan pertumbuhannya. Ia juga menunjukkan bahawa *A. mangium* menjadi sumber penyebaran dan pencerobohan berterusan dan pertumbuhan *A. mangium* berlaku pada kepadatan dan kelimpahan yang lebih besar berbanding dengan tumbuhan asal. *A. mangium* boleh bertukar dengan cepat menjadi ancaman yang serius terhadap biodiversiti tanah hutan sekunder yang terdegradasi yang berhampiran dekat perladangan Akasia

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This thesis was submitted to the Senate of the 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:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

UPM	Universiti Putra Malaysia
UNCBD	United Nation's Convention on Biological Diversity
AHFR	Ayer Hitam Forest Reserve
MARDI	Malaysian Agricultural Research and Development Institute
RUGS	Research University Grant Scheme
USDA	United States Department of Agriculture
FAO	Food and Agriculture Organization
IAS	Invasive alien species
EIS	Exotic Invasive Species
ESI	Exotic Species Invasion
ISSG	Invasive Species Specialist Group
SSC	Species Survival Commission
SGH	Stress-gradient hypothesis
NFS	N-fixing species
OG	Open ground
AM	*Acacia mangium*
TZ	Transition Region
NF	Non-Invaded Natural Forest
GPS	Global Positioning System
Mg	Milligram
m	Meter
ha	Hectares
ml	Milliliter
GWC	Gravimetric water content
OM	Organic Matter

EC	Electrical Conductivity
CEC	Cation-exchange capacity
DS/m	DeciSiemens per meter
Cmol/kg	Centimole per kilogram; also written as cmol(+)kg-1
N	Nitrogen
K	Potassium
Ca	Calcium
Mg	Magnesium
CEC	Cation Exchange Capacity
Sq m	Square metres
Cbh	Circumference at Breast Height
µg	Microgram
Cm	Centimetres
Ht	Height
DBH	Diameter at Breast Height
IVI	Importance Value Indices
IV	Important Value
RD	Relative Density
RF	Relative frequency
RA	Relative abundance
RBA	Relative Basal Area
A/F	Ratio of Abundance to Frequency
H'	Shannon-Weiner Diversity Index
S	Number of species
N	Total Recorded Number of Individuals
Pi	Proportion of Individuals Belonging to Species

Ln	Natural Log (i.e., 2.718)
Cd	Concentration of Dominance
Jsw	Pielou's Evenness Index
Dmg	Margalef's index of species richness
RHGR	Relative Height Growth Rates
RRGR	Radial Growth Rates
Hf	Initial Height
Hi	Final Height
Rf	Initial Diameter
Ri	Final Diameter (Radial)
Tf	Initial Time
Ti	Final Time
Ln	Logarithm
MHa	Million Hectares
NFS	N-fixing species

CHAPTER 1

INTRODUCTION

1.1 Background

Acacia is an extensive genus consisting of over 1300 species that are spread out across tropical and subtropical climates. These species are mostly in the Southern Hemisphere, with Australia and the Pacific exhibiting the greatest diversity. One of these species commonly found in the tropics is *Acacia mangium* willd. *Acacia mangium* is an important and versatile tree in tropical lowlands. Partly due to its rapid growth rate, the tree is widely utilized in forest restoration programs across Asia, the Pacific and the tropical environment (Midgley and Turnbull 2003). *Acacia mangium* is becoming the main source of the commercial supply of tree products. *Acacia plantation*s are nitrogen-fixing with the leaves acting as an ideal litter layer. Trees of *Acacia mangium* have been used effectively in the rehabilitation of soils degraded by the mining of iron, tin, charcoal, copper, gold, and bauxite, particularly in Asia, Australia, and Brazil (Brockwell et al. 2005; Osman 2013; Chiang 2019). *Acacia mangium* is quite versatile and flourishes in various environments including hard compact soils, savannahs, dry ridge tops, slopes, and damp foothills as well as parched barren soils. It has been grown in Malaysia, including poor sites in Sabah, producing better results than other trees (Krisnawati et al. 2011; Sein and Mitlöhner 2011). Despite their benefits in the prevention of soil erosion and windbreakers, these trees can aggressively invade areas beyond their native habitat. Invasive species are classified as those that reproduce very far from their areas of origin taking over large new territories (Bakar 2004; Colautti and MacIsaac 2004). Invasive exotic trees are recognized as the second most significant factor contributing to biodiversity loss after human activities (Dures and Cumming 2010; Richardson and Rejmánek 2011). The impact of the introduction of a non-native species in a territory is not limited to the abiotic characteristics of a given environment but surpasses it to affect the floristic composition of the plant species which can lead to the decline in native species diversity or an increase in the exotic vegetation (Le Maitre et al. 2011).

1.2 Importance of the study

This study was conceptualized to evaluate the distribution of the spatial patterns of the population of Acacia species expanding inside degraded forests of secondary trees in Malaysia, which is characterized by their ability to invade open sites, degraded secondary forests, and agricultural lands.

1.3 Statement of the problems

The genus Acacia has an original distribution across Australia Southeast Asia, and associated islands (Bell et al. 2017) and is one of the many species considered invasive worldwide (Koutika and Richardson 2019). Invasive exotic species are one of the most serious threats to the conservation of native species, communities, and ecosystems (Piria et al. 2017; Ricciardi and Ryan 2018). In the past two decades or so, it has become increasingly clear that exotic *Acacia mangium* used in the commercial and agroforestry industry in Malaysia, has invasive properties that can cause major problems as invaders of natural and semi-natural/disturbed ecosystems as they can become structurally dominant in terrestrial situations (Pimentel 2014). Nonetheless, to be considered invasive, plants must become naturalized, producing a large number of reproductive offspring at considerable distances from the mother plant (>100 m from the original population) in less than 50 years (Richardson et al. 2000). Colautti and MacIsaac (2004) reported that invasive species are those who produce reproductive progenies at substantial distances from source plants, hence their ability to extend to a vast expanse of land. The spread of exotic species beyond their natural habitats has been shown to have a detrimental effect over time (Colautti and MacIsaac 2004). The severity of *A. mangium* invasion into degraded secondary forests is due to its ability to spread its seeds and the higher dormancy rate of its seeds threatens the roles of pioneer or other indigenous species when the forest canopy is opened. By studying the growth and spread of seedlings and saplings in degraded regions of forests and open land, Aguiar et al, 2014 indicated that *A. mangium* can naturally disperse over long distances to 900 m from the plantation edge, independent of its life stage or establishment pattern (Aguiar Jr et al. 2014). Acacia causes changes in the functional diversity of microorganisms in the soil (fungi and root fungi) that hinder the growth of native tree species while restoring degraded lands (Duponnois et al. 2013). These damages are associated with the properties of trees which obstruct the re-establishment of several native species, and therefore, greatly threatening biodiversity (Kueffer et al. 2010; Kueffer et al. 2013). Our monitoring showed that some regions in Ayer Hitam Forest Reserve (AHFR) whereby invasive Acacia trees spreading that occurred naturally were observed along roadsides, old agricultural lands, watercourses, and degraded secondary forests all of which showed indices of invasion. Extensive habitat degradation by anthropogenic factors, deforestation, and dense road networks facilitate Acacia invasion into ecosystems of AHFR. However, in Malaysia, this subject received little attention as studies are limited to the importance of cultivating and developing Acacia plantations in many degraded regions of the country (Simberloff et al. 2010). Therefore, there is a huge shortage of information on the invasion of Acacia trees in Malaysia's native forests and most studies do not contain enough information to explain the invasion of Acacia trees into native forests. Hence, filling this gap of knowledge is useful in determining the scope of the spatial distribution of Acacia trees and their level of invasion.

1.4 Hypotheses Related to Invasions

There are a number of hypotheses that deal with plant invasion ecology. The most common ones regarding Acacia tree species include:

- The propagule pressure dealing with dispersal and geographical constraints. A sufficient number of individuals and/or seeds, as well as a high frequency of introduction events, are both indispensables for a successful invasion (Brzyski 2011; Faithfull 2012; Dormontt 2013; Lachmuth 2019). There is a positive correlation between propagule pressure and the duo of human population density and proximity (Pyšek et al. 2011). It could also explain the necessary delay preceding invasions since there is a general increase in the number of propagules introduced over time (Rejmánek 2000; Simberloff 2009). This factor has been singled out as the major catalyst of invasion.

- The abiotic features related to ecological constraints. Invasion is impossible when species are unable to thrive or overcome the limitations of their new territory. Moreover, many hypotheses that consider environmental factors as precursors to an invasion often make this claim based on of fluctuating resource levels resulting from human or natural disturbances of variable frequency (Menke and Holway 2006). Resource levels are prone to a rise or decline depending on changes in resource supply and the uptake by native species. This involves community invisibility, where the more diverse communities face a lesser risk of invasion because of their higher capacity for biotic resistance and inter-specific competition.

- The biotic features dealing with internal dynamics and population interrelationship. Enemy release, development of competitive ability and invasion meltdown are processes often favourable to invasion. Contrastingly, the absence of mutually beneficial relationships, biotic resistance and antagonism from other dominant native species impedes invasion (Callaway and Aschehoug 2000; Keane and Crawley 2002; Milbau 2005; Bond and Van Wilgen 2012; Tilquin and Kokko 2016). It follows then that this category has a close relationship with the functional characteristics leading to species invasiveness the details can be found in Appendix C.

- The level of severity of the invasion of *A. mangium* into native forests is due to its ability to spread its seeds and the higher dormancy of these seeds may be at an alarming rate which threatens the roles of pioneer or other indigenous species when a forest area is opened.

1.5 General Objectives

This research aims to evaluate the distribution of the spatial patterns of the population of *Acacia mangium* expanding inside degraded secondary forests to understand the ecological impact of the *A. mangium* tree invasion.

1- To compare the soil properties of the soils located under the canopy of the Acacia trees region, the transition region (between the *Acacia mangium* and the native forests), the native forests region, and the open ground region.

2- To estimate and compare the abundance, density, and frequency of seedlings and saplings of the *Acacia mangium* and native forests.

3- To evaluate and compare the growth performance of seedlings and saplings of *Acacia mangium* with that of native forests.

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