



**UNIVERSITI PUTRA MALAYSIA**

***SPATIAL DISTRIBUTION OF ECTOMYCORRHIZAL AND SAPROPHYTIC FUNGI IN RELATION WITH *Shorea leprosula* Miq. SEEDLING SURVIVAL IN DIPTEROCARP FOREST***

**RIRI RIMBUN ANGGIH CHAIDIR**

**IPTPH 2016 5**



**SPATIAL DISTRIBUTION OF ECTOMYCORRHIZAL AND SAPROPHYTIC FUNGI IN RELATION WITH *Shorea leprosula* Miq. SEEDLING SURVIVAL IN DIPTEROCARP FOREST**

By

**RIRI RIMBUN ANGGIH CHAIDIR**

**Thesis Submitted to the School of Graduate Studies,  
Universiti Putra Malaysia, in Fulfilment of the Requirements for the  
Degree of Master of Science**

**June 2016**

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia, unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



Abstract of thesis submission to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science

**SPATIAL DISTRIBUTION OF ECTOMYCORRHIZAL AND SAPROPHYTIC FUNGI IN RELATION WITH *Shorea leprosula* Miq. SEEDLING SURVIVAL IN DIPTEROCARP FOREST**

By

**RIRI RIMBUN ANGGIH CHAIDIR**

**June 2016**

**Chairperson : Professor Ahmad Ainuddin Nuruddin, PhD**  
**Institute : Tropical Forestry and Forest Products**

A central question in community ecology and conservation of highly diverse tropical forests concerns the control of the ability of tree species to coexist. This study explores the possible feedback mechanisms that control *Shorea leprosula* seedling regenerations and survival. This study also proposes a model of asymmetric ectomycorrhizal (EM) positive feedbacks that relies on the assumption of a niche differentiation between EM fungi (EMf) linked to seedlings and EMf linked to EM canopy trees.

This study conducted on a deductive basis of how the mechanisms involved might be supported by the distributions of *S. leprosula* seedlings after a masting event, the percentage of seedling ectomycorrhization and the distributions of saplings below 1 cm diameter that established during previous masting events. Two hypotheses were considered. The first is that the distributions of ectomycorrhizas give benefits to *S. leprosula* seedlings survival correspond to the presence of ectomycorrhizal networks associated to ectomycorrhizal canopy trees. The second is that *S. leprosula* seedlings survival benefits from ectomycorrhizal associations that are independent from the distribution of ectomycorrhizal canopy trees and facilitated by the presence of large saprophytic fungi. Spatial variations of *S. leprosula* seedlings ectomycorrhizal rate didn't support with the first hypothesis. Seedlings ectomycorrhizal rates only increased near to parent trees but not near other ectomycorrhizal canopy trees. Similarly, *S. leprosula* saplings distributions believed to witness seedling survival from previous masting events were either not correlated or negatively correlated with the distribution of ectomycorrhizal canopy trees.

Whereas, the revelation of putative mat-forming and foraging ectomycorrhizal fungi in association with saprophytic fungi agreed with the second hypothesis.

These traits, observed for the first time in a Southeast Asian lowland rainforests concord with a possible ecological niche differentiation between ectomycorrhizal fungi linked to canopy trees and ectomycorrhizal fungi succeeding to saprophytic fungi and possibly contributing to *S. leprosula* seedling survival.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia  
sebagai memenuhi keperluan untuk Ijazah Master Sains

**TABURAN RERUANG KULAT EKTOMIKORIZA DAN SAPROFIT DALAM  
HUBUNGANNYA DENGAN KEMANDIRIAN ANAK BENIH *Shorea leprosula*  
Miq. DI HUTAN DIPTEROKARPA**

Oleh

**RIRI RIMBUN ANGGIH CHAIDIR**

**Jun 2016**

**Pengerusi : Prof. Ahmad Ainuddin Nuruddin, PhD**  
**Institut : Perhutanan Tropika dan Produk Hutan**

Soalan utama dalam ekologi komuniti dan pemuliharaan kepelbagaian hutan tropika adalah berkait pengawalan kemampuan spesies pokok untuk wujud bersama. Kajian ini menerokai mekanisma yang mungkin untuk pengawalan regenerasi dan kemandirian anak pokok *Shorea leprosula*. Kajian ini juga mencadangkan model ektomikoriza (EM) asimetrik yang bergantung kepada andaian pembezaan nic antara kulat ektomikoriza (EMf) yang dikaitkan dengan anak benih dan EMf yang dikaitkan dengan EM pokok kanopi.

Kajian ini dijalankan dengan asas deduktif bagaimana mekanisma yang terlibat mungkin disokong oleh pengagihan anak pokok *S. leprosula* setelah peristiwa musim buah, peratusan ektomikoriza pada anak benih dan pengagihan anak pokok < 1 cm diameter yang hidup daripada peristiwa musim buah sebelumnya. Dua hipotesis dikaji. Pertama, bahawa taburan kulat ektomikoriza memberi manfaat kepada kemandirian anak benih *S. leprosula* terhadap kehadiran jejaring ektomikoriza berkait pokok kanopi ektomikoriza. Kedua, bahawa kemandirian anak benih *S. leprosula* mendapat manfaat dari pada jejaring ektomikoriza yang independen dari pada taburan ektomikoriza yang berasal dari pada pokok kanopi dan dimudahkan dengan kehadiran kulat saprofitik. Variasi reruang kadar ektomikoriza anak benih *S. leprosula* tidak menyokong hipotesis pertama. Kadar ektomikoriza anak benih hanya meningkat dekat dengan pokok kanopi *S. leprosula* tetapi tidak di dekat kawasan pokok ektomikoriza lain. Begitu juga dengan taburan anak pokok *S. leprosula*, yang dipercayai merupakan hasil kemandirian anak benih dari pada musim buah sebelumnya, tidak berkait atau berkait negatif dengan taburan pokok kanopi ektomikoriza

Manakala, penemuan kulat ektomikoriza bentuk met yang memanjang, dalam kaitannya dengan kulat saprofitik, menyokong hipotesis kedua. Sifat-sifat kulat

ini adalah kali pertama diperhatikan di hutan hujan tanah rendah Asia Tenggara, yang menyokong pembezaan niche ekologi antara kulat ektomikoriza berkait pokok kanopi dan ektomikoriza yang meneruskan kulat saprofitik dan mungkin menyokong kemandirian anak benih *S. leprosula*.



## ACKNOWLEDGEMENTS

Alhamdulillah, praise to Allah the Almighty by whose Grace and Permissions that I was able to complete this thesis. Peace be upon the prophet Muhammad S.A.W. All praises to Allah for leading me every step of the way and grace me with this opportunity to further my study.

My sincere gratitude goes to my supervisors, Dr. Ahmad Ainuddin Nuruddin, Dr. Jean Weber, and Dr. Rozi Mohamed for the guidance, advices and supports they put up throughout my study. This study is also made possible by facilities and research aid from INTROP-UPM and financial support by RUGs (Research University Grants) from UPM. I would also thank INTROP-UPM and Department of Land Management of Faculty of Agriculture-UPM staffs and fellow students for helping out in every aspect. I also thanks FRIM for the permission to conduct this study in the 50 ha demographic plot of Pasoh Forest as well as CTFS for granting previous collection of field data used in this study.

I would like to use this opportunity also to thank family and friends with their helps and supports in millions of tiny meaningful ways to build me up. Last but not least, my special thanks to Uda and Bujing Ijah.

I sincerely thank you.

I certify that a Thesis Examination Committee has met on 13 June 2016 to conduct the final examination of Riri Rimbun Anggih Chaidir on her thesis entitled "Spatial Distribution of Ectomycorrhizal and Saprophytic Fungi in Relation with *Shorea leprosula* Miq. Seedling Survival in Dipterocarp Forest" 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

**Hazandy bin Abdul Hamid, PhD**

Associate Professor  
Faculty of Forestry  
Universiti Putra Malaysia  
(Chairman)

**Kamaruzaman bin Sijam, PhD**

Associate Professor  
Faculty of Agriculture  
Universiti Putra Malaysia  
(Internal Examiner)

**Rusea Go, PhD**

Professor  
Faculty of Science  
Universiti Putra Malaysia  
(Internal Examiner)

**Wan Juliana binti Wan Ahmad, PhD**

Associate Professor  
National University of Malaysia  
Malaysia  
(External Examiner)



---

**ZULKARNAIN ZAINAL, PhD**  
Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 23 August 2016

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

**Ahmad Ainuddin Nuruddin, PhD**

Professor  
Institute of Tropical Forestry and Forest Products  
Universiti Putra Malaysia  
(Chairman)

**Jean Joseph Weber, PhD**

Associate Researcher  
Institute of Tropical Forestry and Forest Products  
Universiti Putra Malaysia  
(Member)

**Rozi Mohamed, PhD**

Associate Professor  
Faculty of Forestry  
Universiti Putra Malaysia  
(Member)

---

**BUJANG KIM HUAT, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

## Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature:  \_\_\_\_\_ Date: \_\_\_\_\_

Name and Matric No.: Riri Rimbun Anggih Chaidir (GS28050)

## 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) are adhered to.

Signature: \_\_\_\_\_

Name of  
Chairman of  
Supervisory  
Committee:

Ahmad Ainuddin Nuruddin, PhD

Signature: \_\_\_\_\_

Name of  
Member of  
Supervisory  
Committee:

Jean Joseph Weber, PhD

Signature: \_\_\_\_\_

Name of  
Member of  
Supervisory  
Committee:

Rozi Mohamed, PhD

## TABLE OF CONTENTS

		Page
	<b>ABSTRACT</b>	i
	<b>ABSTRAK</b>	iii
	<b>ACKNOWLEDGEMENTS</b>	v
	<b>APPROVAL</b>	vi
	<b>DECLARATION</b>	viii
	<b>LIST OF TABLES</b>	xiii
	<b>LIST OF FIGURES</b>	xiv
	<b>LIST OF ABBREVIATIONS</b>	xv
<b>CHAPTER</b>		
<b>1</b>	<b>INTRODUCTION</b>	1
<b>2</b>	<b>LITERATURE REVIEW</b>	4
	2.1 Southeast Asian Lowland Dipterocarp Forests	4
	2.2. Diversity and Dominance of the Dipterocarpaceae	5
	2.2.1 Monodominance of ectomycorrhizal species in the tropics	6
	2.2.2 Main mechanisms controlling diversity	7
	2.2.2.1 Mechanisms generating negative feedbacks: density dependant mortality	7
	2.2.2.2 Escaping density dependant mortality	8
	2.2.2.3 Mechanisms generating positive feedbacks	9
	2.2.2.4 Asymmetric positive feedbacks	10
	2.3 Ectomycorrhizal Community in Dipterocarp Forest	10
	2.3.1 Nutrition of the ectomycorrhizal host	13
	2.4 Ectomycorrhizal and Saprophytic Fungi	13
	2.4.1 Source of carbon and ecological niches	13
	2.4.2 Interactions between ectomycorrhizal and saprophytic fungi	14
<b>3</b>	<b>SPATIAL VARIATIONS OF ECTOMYCORRHIZAEA RATES AND LEAF NUTRIENT CONTENTS OF <i>Shorea leprosula</i> Miq. (Dipterocarpaceae) SEEDLINGS IN RELATION TO POSSIBLE FEEDBACK EFFECTS ON TREE REGENERATIONS</b>	16
	3.1 Introduction	16
	3.2 Material and Methods	16
	3.2.1 Study site	17
	3.2.2 Mapping <i>Shorea leprosula</i> below 1 cm diameter at breast height	18
	3.2.3 Ectomycorrhizae sampling	18
		x

3.2.4	Determination of putative ectomycorrhizal tree species	18
3.2.5	Nutrient analysis	18
3.2.6	Spatial correlations between <i>Shorea leprosula</i> saplings quantitative marks and ectomycorrhizal canopy trees	19
3.2.7	Correlations between characteristics of <i>Shorea leprosula</i> saplings	19
3.2.8	<i>Shorea leprosula</i> saplings (below 1 cm dbh) spatial intensity variations	19
3.2.9	Independence between patterns of canopy trees and saplings (below 1 cm dbh)	20
3.3	Results	20
3.3.1	Distributions of <i>Shorea leprosula</i> saplings weight densities and levels of ectomycorrhization	20
3.3.2	Patterns of saplings weight, densities and levels of ectomycorrhization in relation with the distribution of parent and other ectomycorrhizal canopy trees	21
3.3.2.1	Correlations with ectomycorrhizal rates	21
3.3.2.2	Correlations with saplings densities	22
3.3.2.3	Correlations with saplings weights	22
3.3.3	Patterns of saplings nutrient contents in relation with the distribution of parent and other ectomycorrhizal canopy trees	24
3.3.3.1	Correlations in relation to the distribution of <i>Shorea leprosula</i>	24
3.3.3.2	Correlations of the distribution of non- <i>Shorea leprosula</i> ectomycorrhizal trees	26
3.3.3.3	Correlations between nutrient contents and seedlings weight, densities and percentage of ectomycorrhization	26
3.3.4	<i>Shorea leprosula</i> regeneration patterns and their relations with the distribution of parent trees and other ectomycorrhizal canopy trees	28
3.3.4.1	Univariate pattern analysis	28
3.3.4.2	Independence test with <i>Shorea leprosula</i> trees	29
3.3.4.3	Independence test with non- <i>Shorea leprosula</i> ectomycorrhizal trees	29
3.4	Discussion and Conclusions	30
3.4.1	Distribution of putative ectomycorrhizal networks	30
3.4.2	Distributions of seedlings weight and nutrient status	31
3.4.3	Distributions of <i>Shorea leprosula</i> sapling regenerations	32

<b>4</b>	<b>IDENTIFICATION OF LARGE LITTER COLONIZING FUNGI AND THEIR CONCORDANCE WITH THE HYPOTHESIS OF POSSIBLE ECTOMYCORRHIZAL NICHE DIFFERENTIATION</b>	<b>34</b>
	4.1 Introduction	34
	4.2 Materials and Methods	35
	4.2.1 Localization of large litter colonizing fungi	35
	4.2.2 Determination of the genetic identity of the collected sample	37
	4.2.3 Spatial distribution of sampling points in relation to the ectomycorrhizal status of surrounding canopy trees	39
	4.3 Results	39
	4.3.1 Identification of large fungal entities	39
	4.3.2 Genotypes that formed the large fungal communities	45
	4.3.3 Spatial distribution of sampling points in relation to the ectomycorrhizal status of surrounding canopy trees	47
	4.4 Discussion and Conclusions	48
	4.4.1 Fungal sample identification	48
	4.4.2 Concordance of sampled fungus with the hypothesis of a niche differentiation between ectomycorrhizae linked to seedling regeneration and ectomycorrhizae linked to canopy trees	48
<b>5</b>	<b>GENERAL CONCLUSIONS, RECOMMENDATION FOR FUTURE RESEARCH</b>	<b>50</b>
	5.1 General conclusions	50
	5.2 Recommendation for future research	51
	<b>REFERENCES</b>	<b>52</b>
	<b>BIODATA OF STUDENT</b>	<b>67</b>

## LIST OF TABLES

Table		Page
2.1	Published examples of species classical monodominance in Southeast Asian tropical lowland forest environments, with information on traits that have been hypothesized to cause monodominance	5
2.2	Benefits and ecological roles of Ectomycorrhizal fungi	12
3.1	Correlations between <i>Shorea leprosula</i> seedling percentages of ectomycorrhization, shoot dry weight and spatial density. 3.3.3 Patterns of saplings nutrient contents in relation with the distribution of parent and other ectomycorrhizal canopy trees	24
3.2	Correlations between <i>Shorea leprosula</i> seedlings levels of nutrient contents, percentage ectomycorrhization, shoot dry weight and spatial density	28
4.1	Species closest matches of sample sequences submitted to NCBI, UNITE and EMBL with ecological and morphological characteristics and descriptions based on previous studies	40

## LIST OF FIGURES

Figure		Page
2.1	Two differing possible pathways of positive feedbacks leading to monodominance, based on current knowledge	7
2.2	Janzen's (1970) graphical model of the effects of seed predation on tree spacing.	8
2.3	Cleared and stained root hand section (540x Magnification)	11
2.4	Interactions between a saprophytic fungi growing on a wood block and an EM fungi associated to a pine seedling	15
3.1	Sampling points in an experimental sub-plot of 0.47 ha situated in the Pasoh Nature Reserve in Peninsular Malaysia.	17
3.2.	Spatial distributions of <i>Shorea leprosula</i> saplings density, percentage of ectomycorrhization and dry weight.	21
3.3	Bivariate r-mark correlation function $k_{.m^2}(r)$ pattern analysis of %EM, density and saplings weight.	23
3.4	Bivariate r-mark correlation function $k_{.m2}(r)$ pattern analysis for N, P, Mg, K and Ca contents of the saplings stalk and leaves measured in % of dry weight.	25
3.5	Spatial distributions of <i>Shorea leprosula</i> seedling nutrient contents.	27
3.6	<i>Shorea leprosula</i> saplings (below 1 cm dbh) spatial intensity variations tested using the neighborhood density function $O_{11}(r)=\lambda_1 g_{11}(r)$ with 2 m wide rings.	29
3.7	Independence test between patterns of canopy trees and saplings (below 1 cm dbh).	30
4.1	One of large patches of mat forming fungi in Pasoh forest floor during observation.	35
4.2	Saprophytic fungi on forest litter, samples taken were marked with labels.	36
4.3	Sampling map of 4 locations within 50 ha FRIM Plot in Pasoh Forest Reserve	36
4.4	Individual sampling maps of big fungal patch locations	37
4.5	Phylogenetic tree of original sample sequences with annotated trophic status of corresponds to species outputs of (D, P, QA and QB).	46

- 4.6 O12(r) function expressing the density of the ectomycorrhizal status of canopy trees > 20 cm dbh in the neighborhood of the sampling points. 47



## LIST OF ABBREVIATIONS

%EM	Percentage of visible ectomycorrhization
AM	Arbuscular mycorrhizal
BLAST	Basic Local Alignment Search Tool
C	Carbon
C/N	Carbon to Nitrogen ratio
Ca	Calcium
CSR	Complete spatial randomness
CTAB	Cetyl trimethylammonium bromide
CTFS	Center for Tropical Forest Science
DNA	Deoxyribonucleic acid
dNTPs	Deoxyribose nucleoside triphosphate
EM	Ectomycorrhizal, Ectomycorrhiza
EMBL-ENA	European Molecular Biology Laboratory - European Nucleotide Archive
EMf	Ectomycorrhizal fungi
FRIM	Forest Research Institute Malaysia
ITS	Internal transcribed spacer
K	Kalium/Potassium
Mg	Magnesium
MgCl <sub>2</sub>	Magnesium Chloride
N	Nitrogen
NCBI	National Center for Biotechnology Information
P	Phosphorus
PCR	Polymerase chain reaction
SAP	Saprotrophic, Saprophytic, Saprotrophs
TBE	Tris/Borate/EDTA
UNITE	Unified system for the DNA based fungal species linked to the classification
UV	Ultraviolet
$\delta^{13}\text{C}$	Measure of the ratio of stable Carbon isotopes $^{13}\text{C}$ : $^{12}\text{C}$
$\mu\text{L}$	Microliter

## CHAPTER I

### INTRODUCTION

*Shorea leprosula* Miq. is a common canopy species in the lowland forests of Southeast Asia (Lee *et al.*, 1997). As the most member of the Dipterocarpaceae, *S. leprosula* is characterized by ectomycorrhizal (EM) associations (Lee and Alexander, 1996), limited wind dispersion due to relative high area-to-mass ratio of winged nuts (Seidler and Plotkin, 2006) and mast fruiting at irregular intervals of several years (Ashton *et al.*, 1988). All these traits have been hypothesized to reinforce tree species dominance in the tropics (Ashton *et al.*, 1988). However, if tropical dominance is elsewhere represented by one or a few species on a limited area (Peh *et al.*, 2011), dipterocarp forests are dominated at the family level with up to several tens of dipterocarp species occupying 40 to 80% of the large-tree components and this is in mostly Southeast Asian lowland regions (Corlett, 2009; Kochummen *et al.*, 1990). In addition, the intensity and constancy of this family dominance has allowed sufficient space for species of other tree families to coexist and for dipterocarp forests to count among the most species-rich on the planet (Primack and Corlett, 2005). A commonly hypothesized mechanism of species coexistence is when intra-specific competition exceeds inter-specific competition (Chesson, 2000). This is illustrated by the Janzen-Connell hypothesis where distance and density-dependent seedling mortality increase intra-specific negative feedback (Connell, 1971; Janzen, 1970).

This mechanism, proposed for both EM and non-EM tree species occurs when for example predators or pathogens regulate the regeneration of each species independently (Comita *et al.*, 2014). Conversely, symbiotic associations are believed to generate positive feedbacks, thus are able to reinforce dominances (May, 1973). It has for example been proposed that seedlings associated to EM networks supported by photosynthates of canopy trees may increase their fitness through a better access to nutrients and water at lower carbon expenses (Booth and Hoeksema, 2010; McGuire, 2014 and 2007; Nara, 2006). The effect of positive feedbacks attributed to EM networks on the monodominance of a single tropical species has been illustrated in more than ten studies involving eleven species in tropical forests of America, Africa and Southeast Asia (McGuire, 2014). However, hypotheses about possible roles of EMf associations in the maintenance of dominance at family level in Southeast Asian dipterocarp forests have, to my knowledge, not been specifically studied. In Southeast Asian lowland forests, most of the EM trees are Dipterocarpaceae with no clear evidence found for EM species-specificities (Alexander and Lee, 2005). In this context, it could be theorized that EM networks associated to canopy trees may potentially benefit to the establishment of EM seedlings from different surrounding species. Such positive feedback could lead to family dominance if not counteracted by negative feedback expressed at the same level (Alexander and Lee, 2005).

Negative feedback is also suggested to have the ability in maintaining diversity by counteracting with monodominance (Bever, 1999). Bever (1999) suggested that negative feedbacks may result from an asymmetric delivery of positive feedbacks to mutualistic competitors. This kind of mechanisms has for example been demonstrated in grassland where arbuscular mycorrhizal (AM) fungus that develops best with *Plantago lanceolata* which grows at best with an AM fungi associated to *Panicum sphaerocarpon* (Bever, 2002). It can be conjectured that in dipterocarp forests, asymmetric feedbacks to EM seedling regenerations may occur and prevent EM monodominance if EM seedlings benefit from EM fungi having different ecological niche and spatial distribution than EM fungi associated to EM canopy trees. This may happen in the case of an association of EM seedlings with facultative EM fungi (Baldrian, 2009), which capable of obtaining carbon both biotrophically and saprotrophically (Koide *et al.*, 2008; Lindahl and Tunlid, 2015) and a spatial differentiation between obligatory EM occurring under the canopies of EM trees and facultative EM capable to survive in the understory of non EM canopy trees.

In the present study, the concordance of hypothesized roles of EMf in the maintenance of Dipterocarpaceae dominance in Southeast Asian lowland forests will be discussed in relation with the spatial distributions of *S. leprosula* seedlings, seedling nutrient contents, seedlings EM rates, saplings as well as the spatial distribution of canopy trees ectomycorrhizal status within a 0.47 ha subplot of the 50 ha demographic forest plot of Pasoh in Negeri Sembilan – Malaysia. The existence of heterogeneities in the distribution of putative EM networks associated to canopy trees compatible with the hypothesis of an ectomycorrhizal spatial niche differentiation is estimated by correlating the EM rates two-leave-stage *S. leprosula* saplings with the distance to the nearest parent tree.

Furthermore, the distribution and species composition of presumed large litter saprotrophs occurring within the 50 ha demographic plot will be studied for a possible concordance with the hypothesis of a spatial niche differentiation of EMf associated to seedlings from EM associated to canopy trees. The choice of a deductive approach for this study is in line with the method of census plots used by the Smithsonian Center of Tropical Forest Science (CTFS) for the examination of ecological theories on the maintenance of high species diversity (Condit, 1998). Natural processes are therefore not disturbed by the establishment of experimental layouts such as soil mesh insertions to control the effect of EM networks between plants, seedling transplantation or soil sterilization.

## **Objectives**

The aim of this study is to evaluate the concordance of spatial distributions of ectomycorrhizal and saprophytic fungi in relation with hypotheses of *S. leprosula* seedling recruitments and maintenance of Dipterocarpaceae dominance by the delivery of EM asymmetric positive feedbacks. In the first

part of the study (Chapter III), possible mechanisms of seedlings survival were discussed in several points: 1) the spatial distributions of seedlings EM rates; 2) spatial heterogeneities of putative EM networks associated to EM canopy trees; 3) the presence of possible EM host specificities; 4) the spatial distributions of conditions for density-dependant seedling mortality; and 5) spatial patterns of sapling recruitments witnessing seedling survival from previous masting events.

In Chapter 4, the second part of the study, the nature and distribution of large patches of presumed litter saprotrophs will be examined for their suitability to facilitate the succession of EMf linked to *S. leprosula* seedlings. Such succession would support a possible possible niche differentiation between EMf linked to seedling regeneration and EMf linked to canopy trees and support the hypothesis of a family dominance regulated by a asymmetric EM positive feedback.

## REFERENCES

- Abuzinadah, R.A., Finlay, R.D. and Read, D.J. 1986. The role of proteins in the nitrogen nutrition of ectomycorrhizal plants. *New Phytologist* 103(3): 495-506. DOI: 10.1111/j.1469-8137.1986.tb02887.x
- Agerer, R. 2001. Exploration types of ectomycorrhizae: A proposal to classify ectomycorrhizal mycelial systems according to their patterns of differentiation and putative ecological importance. *Mycorrhiza* 11:107–114. DOI: 10.1007/s005720100108
- Alexander, I. 1989. Mycorrhizas in tropical forests. Reprinted from Mineral Nutrients in Tropical Forest and Savana Ecosystems. *Special Publication Number 9 of the British Ecological Society*. Ed J. Proctor. Blackwell Scientific Publication.
- Alexander, I., Norani, A. and Lee, S.S. 1992. The role of mycorrhizas in the regeneration of some Malaysian forest trees. *Philosophical Transactions of the Royal Society, London B* 335: 379-388. DOI: 10.1098/rstb.1992.0029
- Alexander, I.J. and Lee, S.S. 2005. Mycorrhizas and ecosystem processes in tropical rain forest: implications for diversity. In: Burslem, D.F.R.P, Pinard, M.A., Hartley, S.E., eds. *Biotic interactions in the tropics: their role in the maintenance of species diversity*. London, UK: Cambridge University Press: 165–203. DOI: 10.1017/CBO9780511541971.008
- Allison, V.J., Yermakov, Z., Miller, R.M., Jastrow, J.D. and Matamala, R. 2007. Using landscape and depth gradients to decouple the impact of correlated environmental variables on soil microbial community composition. *Soil Biology and Biochemistry* 39(2): 505-516. DOI: 10.1016/j.soilbio.2006.08.021.
- Altschul, S.F., Gish, W., Miller, W., Myers, E.W. and Lipman, D.J. 1990. Basic local alignment search tool. *Journal of molecular biology* 215(3): 403-410. DOI: 10.1016/S0022-2836(05)80360-2
- Antonín, V. and Buyck, B. 2006. Marasmius (Basidiomycota, Marasmiaceae) in Madagascar and the Mascarenes. *Fungal Diversity* 23:17-50.
- Appanah, S. 1993. Mass flowering of dipterocarp forests in the aseasonal tropics. *Journal of Bioscience* 18 (4): 457-474. DOI: 10.1007/BF02703079
- Appanah, S. 1998. Management of natural forests. In: Appanah, S. and Turnbull, J.M., eds. *A Review of Dipterocarps: Taxonomy, Ecology and Silviculture*: 133-150. CIFOR Publications, Indonesia.
- Appanah, S. and Turnbull, J.M. 1998. *A Review Of Dipterocarps*. Bogor, Indonesia: Center for International Forestry Research. DOI: 10.17528/cifor/000463
- Ashton, P.M.S. 1992. Some measurements of the microclimate in a Sri Lanka tropical rainforest. *Agriculture and Forest Meteorology and Management* 36: 163-175
- Ashton, P.M.S. 1995. Seedling growth of co-occurring *Shorea* species in stimulated light environments of a rain forest. *Forest Ecology and Management* 72: 1-12.
- Ashton, P.S. 1982. Dipterocarpaceae 9 (2): 237-552

- Ashton, P.S. 1988. Dipterocarp biology as a window to the understanding of tropical forest structure. *Annual Review of Ecology and Systematics*: 347-370.
- Augsburger, C.K. 1984. Seedling Survival of Tropical Tree Species: Interactions of Dispersal Distance, Light-Gaps, and Pathogens. *Ecology* 65:1705-1712. DOI: 10.2307/1937766
- Augsburger, C.K. and Kitajima, K. 1992. Experimental Studies of Seedling Recruitment from Contrasting Seed Distributions. *Ecology* 73 (4): 1270–1284. DOI: 10.2307/1940675
- Bâ, A. M., Garbaye, J., Martin, F. and Dexheimer, J. 1994. Root soluble carbohydrates of *Azelia africana* Sm. seedlings and modifications of mycorrhiza establishment in response to the excision of cotyledons. *Mycorrhiza* 4: 269-275. DOI: 10.1007/BF00206776
- Bais, H.P., Park, S.W., Weir, T.L., Callaway, R.M. and Vivanco, J.M. 2004. How plants communicate using the underground information superhighway. *Trends in plant science* 9(1): 26-32.
- Bais, H.P., Weir, T.L., Perry, L.G., Gilroy, S. and Vivanco, J.M. 2006. The role of root exudates in rhizosphere interactions with plants and other organisms. *Annual Review of Plant Biology* 57: 233-266. DOI: 10.1146/annurev.arplant.57.032905.105159
- Baldrian, P. 2009. Ectomycorrhizal fungi and their enzymes in soils: is there enough evidence for their role as facultative soil saprotrophs?. *Oecologia* 161(4): 657-660. DOI: 10.1007/s00442-009-1433-7
- Baltzer, J.L. and Davies, S.J. 2012. Rainfall seasonality and pest pressure as determinants of tropical tree species' distributions. *Ecology and evolution* 2(11): 2682-2694. DOI: 10.1002/ece3.383
- Bebber, D.P., Hynes, J., Darrah, P.R., Boddy, L. and Fricker, M.D. 2007. Biological solutions to transport network design. *Proceedings of the Royal Society of London B: Biological Sciences* 274(1623): 2307-2315. DOI: 10.1098/rspb.2007.0459
- Bechtold, T. and Mussak, R. 2009. eds.. *Handbook of natural colorants*. John Wiley & Sons.
- Bellion, M., Courbot, M., Jacob, C., Blaudez, D. and Chalot, M. 2006. Extracellular and cellular mechanisms sustaining metal tolerance in ectomycorrhizal fungi. *FEMS microbiology letters* 254(2): 173-181. DOI: 10.1111/j.1574-6968.2005.00044.x
- Berglund, H., Edman, M. and Ericson, L. 2005. Temporal variation of wood-fungi diversity in boreal old-growth forests: implications for monitoring. *Ecological Applications* 15(3): 970-982. DOI: 10.1111/j.1523-1739.2005.00550.x
- Bernicchia, A., Savino, E. and Gorjon, S.P., 2007. Aphyllophoraceous wood-inhabiting fungi on *Pinus* spp. in Italy. *Mycotaxon* 101: 5-8. DOI: 10.1016/j.tplants.2003.11.008
- Bever, J.D. 1999. Dynamics within mutualism and the maintenance of diversity: inference from a model of interguild frequency dependence. *Ecology Letters* 2: 52-61. DOI: 10.1046/j.1461-0248.1999.21050.x
- Bever, J.D. 2002. Negative feedback within a mutualism: host-specific growth of mycorrhizal fungi reduces plant benefit. *Proceedings of the Royal Society B: Biological Sciences* 269: 2595-2601. DOI:10.1098/rspb.2002.2162.

- Bever, J.D., Dickie, I.A., Facelli, A., Facelli, J.M. Klironomos, J., Moora, M., Rillig, M.C., Stock, W.D., Tibbett, M. and Zobel, M. 2010. Rooting Theories of Plant Community Ecology in Microbial Interactions. *Trends in Ecology and Evolution* 25: 468–478. DOI: 10.1016/j.tree.2010.05.004
- Blackwell, M. 2011. The fungi: 1, 2, 3 ... 5.1 million species? *American Journal of Botany* 98 (3): 426-438. DOI: 10.3732/ajb.1000298
- Blundell, A.G. and Peart, D.R. 2001. Growth strategies of a shade-tolerant tropical tree: the interactive effects of canopy gaps and simulated herbivory. *Journal of Ecology* 89(4): 608-615. DOI: 10.1046/j.0022-0477.2001.00581.x
- Boddy, L. 1993. Saprotrophic cord-forming fungi: warfare strategies and other ecological aspects. *Mycological Research* 97: 641–655. DOI: 10.1016/S0953-7562(09)80141-X
- Bödeker, I.T., Nygren, C.M., Taylor, A.F., Olson, Å. and Lindahl, B.D. 2009. Class II peroxidase-encoding genes are present in a phylogenetically wide range of ectomycorrhizal fungi. *The ISME Journal* 3(12): 1387-1395. DOI: 10.1111/nph.12791
- Booth, M.G. 2004. Mycorrhizal networks mediate overstorey-understorey competition in a temperate forest. *Ecology Letters* 7(7): 538-546. DOI: 10.1111/j.1461-0248.2004.00605.x
- Booth, M.G. and Hoeksema, J.D., 2010. Mycorrhizal networks counteract competitive effects of canopy trees on seedling survival. *Ecology* 91(8): 2294-2302.
- Brazanti, M.B., Rocca, E. and Pisi, A. 1999. Effect of ectomycorrhizal fungi on chestnut ink disease. *Mycorrhiza* 9: 103-109. DOI: 10.1007/s005720050007.
- Brown, D., 1992. Estimating the composition of a forest seed bank: a comparison of the seed extraction and seedling emergence methods. *Canadian Journal of Botany* 70(8): 1603-1612. DOI: 10.1139/b92-202
- Brummitt, R.K. 2001. World Geographical Scheme for Recording Plant Distributions: Edition 2. International Working Group on Taxonomic Databases for Plant Sciences (TDWG) [Electronic version]. Retrieved 2006-11-27.
- Brundrett, M., Bougher, N., Dell, B. and Grove, T. 1996. Working with Mycorrhizas in Forestry and Agriculture.
- Brundrett, M.C. and Cairney, J. 2002. Ectomycorrhizas in plant communities. In Sivasithamparam, K., Dixon, K.W. and Barrett, R.L. eds. *Microorganisms in plant conservation and biodiversity*: 105–150.
- Bruns, T.D., Szaro, T.M., Gardes, M., Cullings, K.W., Pan, J.J., Taylor, D.L., Horton, T.R., Kretzer, A., Garbelotto, M. and Li, Y. 1998. A sequence database for the identification of ectomycorrhizal basidiomycetes by phylogenetic analysis. *Molecular Ecology* 7(3): 257-272.
- Bruns, T.D., White, T.J. and Taylor, J.W. 1991. Fungal molecular systematics. *Annual Review of Ecology and systematics*: 525-564.
- Buée, M., Courty, P.E., Mignot, D. and Garbaye, J. 2007. Soil niche effect on species diversity and catabolic activities in an ectomycorrhizal fungal community. *Soil Biology and Biochemistry* 39(8): 1947-1955. DOI:10.1016/j.soilbio.2007.02.016

- Buée, M., Vairelles, D. and Garbaye, J. 2005. Year-round monitoring of diversity and potential metabolic activity of the ectomycorrhizal community in a beech (*Fagus sylvatica*) forest subjected to two thinning regimes. *Mycorrhiza* 15(4): 235-245. DOI: 10.1007/s00572-004-0313-6
- Cardoso I.M. and Kuyper, T.W. Mycorrhizas and tropical soil fertility. 2006. *Agriculture, Ecosystem and Environment* 116: 72–84. DOI: 10.1016/j.agee.2006.03.011
- Chalot, M. and Brun, A. 1998. Physiology of organic nitrogen acquisition by ectomycorrhizal fungi and ectomycorrhizas. *FEMS Microbiology Reviews* 22(1): 21-44. DOI: 10.1111/j.1574-6976.1998.tb00359.x
- Chen, D.M. and Cairney, J.W.G. 2002 Investigation of the influence of prescribed burning on ITS profiles of ectomycorrhizal and other soil fungi at three Australian sclerophyll sites. *Mycological Research* 106: 532–540. DOI: 10.1017/S0953756202005890
- Chesson, P. 2000. Mechanisms of Maintenance of Species diversity. *Annual Review of Ecology and Systematics* 31: 342-66. DOI: 10.1146/annurev.ecolsys.31.1.343
- Comita, L.S., Queenborough, S.A., Murphy, S.J., Eck, J.L., Xu, K., Krishnadas, M., Beckman, N. and Zhu, Y. 2014. Testing predictions of the Janzen–Connell hypothesis: a meta-analysis of experimental evidence for distance-and density-dependent seed and seedling survival. *Journal of Ecology* 102(4): 845-856. DOI: 10.1111/1365-2745.12232
- Condit, R. 1998. Tropical Forest Census Plots: Methods and Results from Barro Colorado Island, Panama and a Comparison with Other Plots. Springer-Verlag. DOI: 10.1007/978-3-662-03664-8
- Connell, J.H. 1971. On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. *Dynamics of populations*: 298-312.
- Connell, J.H. and Lowman, M.D. 1989. Low-diversity tropical rain forests: some possible mechanisms for their existence. *The American Naturalist* 13 (1): 88–119.
- Corlett, R.T. 2009. Seed dispersal distances and plant migration potential in tropical East Asia. *Biotropica* 41(5): 592-598. DOI: 10.1111/j.1744-7429.2009.00503.x
- Cornejo, J. and Hermosin, M.C. 1996. Interaction of humic substances and soil clays. PICCOLO, A. Humic substances in terrestrial ecosystems: 595-624. Amsterdam: Elsevier.
- Cullings, K.W., New, M.H., Makhija, S. and Parker, V.T. 2003. Effects of litter addition on ectomycorrhizal associates of a lodgepole pine (*Pinus contorta*) stand in Yellowstone National Park. *Applied and environmental microbiology* 69(7): 3772-3776. DOI: 10.1128/AEM.69.7.3772-3776.2003
- Dahm, H. and Golińska, P. 2011. Ectomycorrhiza and secondary metabolites. In *Diversity and Biotechnology of Ectomycorrhizae*: 371-385. Springer Berlin Heidelberg.
- Dai, Y.C. and Cui, B.K. 2011. *Fomitiporia ellipsoidea* has the largest fruiting body among the fungi. *Fungal Biology* 115: 813–814. DOI: 10.1016/j.funbio.2011.06.008.

- Dakora, F.D. and Phillips, D.A. 2002. Root exudates as mediators of mineral acquisition in low-nutrient environments. *Plant and soil* 245(1): 35-47.
- Davies, S.J., Supardi, M.N.N., LaFrankie, J.V. and Ashton, P.S. 2003. The trees of Pasoh forest: stand structure and floristic composition of the 50-ha forest research plot. In Okuda, T., Manokaran, N., Matsumoto, Y., Niiyama, K., Thomas, S.C. and Ashton, P.S. eds. *Pasoh: Ecology of a Lowland Rain Forest in Southeast Asia*: 35 – 50. Springer-Verlag, Tokyo. DOI: 10.1007/978-4-431-67008-7\_3
- De Roman, M., Claveria, V. and De Miguel, A.M. 2005. A revision of the descriptions of ectomycorrhizas published since 1961. *Mycological Research* 109(10): 1063-1104. DOI: 10.1017/S0953756205003564
- Delissio, L.J. and Primack, R.B. 2003. The impact of drought on the population dynamics of canopy-tree seedlings in an aseasonal Malaysian rainforest. *Journal of Tropical Ecology* 19 (05): 489–500. DOI: 10.1017/S0266467403003547.
- Denslow, J.S. 1987. Tropical rainforest gaps and tree species diversity. *Annual review of ecology and systematics*: 431-451.
- Dunham, S.M., Larsson, K.H. and Spatafora, J.W. 2007. Species richness and community composition of mat-forming ectomycorrhizal fungi in old-and second-growth Douglas-fir forests of the HJ Andrews Experimental Forest, Oregon, USA. *Mycorrhiza* 17(8): 633-645. DOI: 10.1007/s00572-007-0141-6
- Engelbrecht, B.M.T, Comita, L.S., Condit, R., Kursar, T.A., Tyree, M.T. Turner, B.L. and Hubbell, S.P. 2007. Drought sensitivity shapes distribution patterns in tropical forests. *Nature* 447: 80-82. DOI: 10.1038/nature05747
- Entry, J.A., Rose, C.L. and Cromack, K. 1991. Litter decomposition and nutrient release in ectomycorrhizal mat soils of a Douglas fir ecosystem. *Soil Biology and Biochemistry* 23(3): 285-290. DOI: 10.1016/0038-0717(91)90065-R
- Estrada-Torres, A., Gaither, T.W., Miller, D.L., Lado, C. and Keller, H.W. 2005. The myxomycete genus *Schenella*: morphological and DNA sequence evidence for synonymy with the gasteromycete genus *Pyrenogaster*. *Mycologia* 97(1): 139-149. DOI: 10.3852/mycologia.97.1.139
- Fitter, A.H. and Garbaye, J. 1994. Interactions between mycorrhizal fungi and other soil organisms. *Plant and Soil* 159: 123-132. DOI: 10.1007/BF00000101
- Gardes, M. and Bruns, T.D. 1993. ITS primers with enhanced specificity for basidiomycetes-application to the identification of mycorrhizae and rusts. *Molecular ecology* 2(2): 113-118.
- Graves, J.D., Watkins, N.K., Fitter, A.H., Robinson, D. and Scrimgeour, C. 1997. Intraspecific transfer of carbon between plants linked by a common mycorrhizal network. *Plant and soil* 192: 153-159. DOI: 10.1023/A:1004257812555
- Griffiths, R.P. and Caldwell, B.A. 1992. Mycorrhizal mat communities in forest soils. *Mycorrhizas in ecosystems*: 98-105.
- Griffiths, R.P., Ingham, E.R., Caldwell, B.A., Castellano, M.A. and Cromack Jr, K. 1991. Microbial characteristics of ectomycorrhizal mat

- communities in Oregon and California. *Biology and Fertility of Soils* 11(3): 196-202. DOI: 10.1007/BF00335767
- Grubb, P.J. 1977. The maintenance of species-richness in plant communities: the importance of the regeneration niche. *Biology Review* 52: 107-145. DOI: 10.1111/j.1469-185X.1977.tb01347.x
- Grubb, P.J., Turner, I.M. and Burslem, D.F.R.P. 1994. Mineral nutrient status of coastal hill dipterocarp forest and adinandra belukar in Singapore: analysis of soil, leaves and litter. *Journal of Tropical Ecology* 10(04): 559-577.
- Guehl, J.M. and Garbaye, J. 1990. The effects of ectomycorrhizal status on carbon dioxide assimilation capacity, water-use efficiency and response to transplanting in seedlings of *Pseudotsuga menziesii* (Mirb) Franco. *Annales des sciences forestières* 47(6): 551-563 EDP Sciences.
- Guevara, R. and Romero, I. 2004. Spatial and temporal abundance of mycelial mats in the soil of a tropical rain forest in Mexico and their effects on the concentration of mineral nutrients in soils and fine roots. *New phytologist* 163(2): 361-370. DOI: 10.1111/j.1469-8137.2004.01099.x
- Hall, T.A. 1999, January. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. In *Nucleic acids symposium series* 41: 95-98.
- Harms, K.E., Wright, S.J., Calderón, O., Hernández, A. and Herre, E.A. 2000. Pervasive density-dependent recruitment enhances seedling diversity in a tropical forest. *Nature* 404(6777): 493-495. DOI: 10.1038/35006630
- Hart, T.B. 1990. Monospecific dominance in tropical rain forests. *Trends in Ecology & Evolution* 5(1): 6-11. DOI: 10.1016/0169-5347(90)90005-X
- Hart, T.B., Hart, J.A. and Murphy, P.G. 1989. Monodominant and species-rich forests of the humid tropics: cause for their co-occurrence. *The American naturalist* 133 (5): 613-633. DOI: 10.1086/284941
- Hawker, L.E. 1974. Revised annotated list of British hypogeous fungi. *Transactions of the British Mycological Society* 63(1): 67-76. DOI: 10.1016/S0007-1536(74)80136-1
- He, X.H., Critchley, C. and Bledsoe, C. 2003. Nitrogen transfer within and between plants through common mycorrhizal networks (CMNs). *Critical Reviews in Plant Sciences* 22 (6): 531-567. DOI: 10.1080/713608315
- Henkel, T.W. 2002. Monodominance in ectomycorrhizal *Dicymbecorymbosa* (Caesalpiaceae) from Guyana. *Journal of tropical ecology* 19: 417-437. DOI: 10.1017/S0266467403003468
- Henkel, T.W., Mayor, J.R. and Woolley, L.P. 2005. Mast fruiting and seedling survival of the ectomycorrhizal, monodominant *Dicymbe corymbosa* (Caesalpiaceae) in Guyana. *New Phytologist* 167(2): 543-556. DOI: 10.1111/j.1469-8137.2005.01431.x
- Hibbett D.S., Gilbert L.B., Donoghue, M.J. 2000. Evolutionary instability of ectomycorrhizal symbioses in basidiomycetes. *Nature* 407: 506–508. DOI: 10.1038/35035065
- Hibbett, D.S., Bauer, R., Binder, M., Giachini, A.J., Hosaka, K., Justo, A., Larsson, E., Larsson, K.H., Lawrey, J.D., Miettinen, O. and Nagy,

- L.G. 2014. 14 Agaricomycetes. In *Systematics and evolution*: 373-429. Springer Berlin Heidelberg.
- Hobbie, E. A. 2006. Carbon allocation to ectomycorrhizal fungi correlates with belowground allocation in culture studies. *Ecology* 87(3): 563–569
- Högberg, M.N. and Högberg, P. 2002. Extramatrical ectomycorrhizal mycelium contributes half the microbial biomass and produces, together with associated roots, half the dissolved organic carbon in afforest soil. *New Phytologist* 154: 791–795. DOI: 10.1046/j.1469-8137.2002.00417.x
- Högberg, P., Plamboeck, A.H., Taylor, A.F. and Fransson, P.M. 1999. Natural <sup>13</sup>C abundance reveals trophic status of fungi and host-origin of carbon in mycorrhizal fungi in mixed forests. *Proceedings of the National Academy of Sciences* 96(15): 8534-8539.
- Horton, T.R. and Bruns, T.D. 2001. The molecular revolution in ectomycorrhizal ecology: peeking into the black-box. *Molecular ecology* 10(8): 1855-1871. DOI: 10.1046/j.0962-1083.2001.01333.x
- Horton, T.R. and Bruns, T.D. 1998. Multiple-host fungi are the most frequent and abundant ectomycorrhizal types in a mixed stand of Douglas fir (*Pseudotsuga menziesii*) and bishop pine (*Pinus muricata*). *New Phytologist* 139(2): 331-339. DOI: 10.1046/j.1469-8137.1998.00185.x
- Hosaka, K., Castellano, M.A. and Spatafora, J.W. 2008. Biogeography of Hysterangiales (Phallomycetidae, Basidiomycota). *Mycological Research* 112(4): 448-462. DOI: 10.3852/mycologia.98.6.949
- Hubbell, S.P. and Foster, R.B. 1992. Short-term dynamics of a neotropical forest: why ecological research matters to tropical conservation and management. *Oikos*: 48-61. DOI: 10.2307/3545515
- Hubbell, S.P. 1980. Seed predation and the coexistence of tree species in tropical forests. *Oikos*: 214-229. DOI: 10.2307/3544429
- Ibekwe, A.M., Kennedy, A.C., Frohne, P.S., Papiernik, S.K., Yang, C.H. and Crowley, D.E. 2002. Microbial diversity along a transect of agronomic zones. *FEMS Microbiology Ecology* 39(3): 183-191. DOI: 10.1111/j.1574-6941.2002.tb00921.x
- Itoh, A. 1995. Regeneration processes and coexistence mechanisms of two Bornean emergent dipterocarp species. DOI: 10.11501/3102646
- Itoh, A., Yamakura, T., Ogino, K., Lee, H.S. and Ashton, P.S. 1997. Spatial distribution patterns of two predominant emergent trees in a tropical rainforest in Sarawak, Malaysia. *Plant Ecology* 132(2): 121-136.
- Janzen, D.H. 1970. Herbivores and the number of tree species in tropical forests. *The American Naturalist* 104: 501–528. DOI: 10.1086/282687
- Jentschke, G., Brandes, B., Kuhn, A.J., Schröder, W.H. and Godbold, D.L. 2001. Interdependence of phosphorus, nitrogen, potassium and magnesium translocation by the ectomycorrhizal fungus *Paxillus involutus*. *New Phytologist* 149(2): 327-337. DOI: 10.1046/j.1469-8137.2001.00014.x
- Kachi, N., Okuda, T. and Yap, S.K. 1993. Seedling establishment of a canopy tree species in Malaysian tropical rain forests. *Plant Species Biology* 8(2-3): 167-174. DOI: 10.1111/j.1442-1984.1993.tb00068.x

- Kluber, L., Tinnesand, K.M., Caldwell, B.A., Dunham, S.M, Yarwood, R.R., Bottomley, P.J. and Myrold, D.D. 2010. Ectomycorrhizal mats alter forest soil biogeochemistry. *Soil Biology and Biochemistry* 42: 1607-1613. DOI: 10.1016/j.soilbio.2010.06.001
- Kochummen, K.M. 1997. *Tree flora of Pasoh forest* (No. 44). Forest Research Institute Malaysia.
- Kochummen, K.M., LaFrankie Jr, J.V. and Manokaran, N. 1990. Floristic composition of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science*: 1-13.
- Koide, R.T., Sharda, J.N., Herr, J.R. and Malcolm, G.M. 2008. Ectomycorrhizal fungi and the biotrophy-saprotrophy continuum. *New Phytologist* 178: 230-233. DOI: 10.1111/j.1469-8137.2008.02401.x
- Kottke, I. 2004. The Surface of Ectomycorrhizal Roots and the Interaction with Ectomycorrhizal Fungi. In Varma, A., Abbott, L., Werner, D. and Hampp, R. eds. *Plant Surface Microbiology*: 211-226. Springer Berlin, Heidelberg, DOI: 10.1007/978-3-540-74051-3\_13
- Kottke, I. and Oberwinkler, F. 1986. Mycorrhiza of forest trees—structure and function. *Trees* 1(1): 1-24. DOI: 10.1007/BF00197021
- Kottke, I. and Oberwinkler, F. 1986. Root-fungus interactions observed on initial stages of mantle formation and Hartig net establishment in mycorrhizas of *Amanita muscaria* on *Picea abies* in pure culture. *Canadian Journal of Botany* 64 (10): 2348-2354. DOI: 10.1139/b86-308
- Kottke, I. and Oberwinkler, F. 1988. Comparative studies on the mycorrhization of *Larix decidua* and *Picea abies* by *Suillus grevillea*. *Trees* 2: 115-128. DOI: 10.1007/BF00196758
- Kottke, I. and Oberwinkler, F. 1989. Amplification of root-fungus interface in ectomycorrhizae by Hartig net architecture. *Annals of Forest Science* 46: 737-740. DOI: 10.1051/forest:198905ART0164
- Lee, L.S., Alexander, I.J. and Watling, R. 1997. Ectomycorrhizas and putative ectomycorrhizal fungi of *Shorea leprosula* Miq. (Dipterocarpaceae). *Mycorrhiza* 7(2): 63-81. DOI: 10.1007/s005720050165
- Lee, S.S. and Alexander, I.J. 1996. The dynamics of ectomycorrhizal infection of *Shorea leprosula* seedlings in Malaysian rain forests. *New Phytologist* 132(2): 297-305. DOI: 10.1111/j.1469-8137.1996.tb01849.x
- Lee, S.S. and Alexander, I.J. 1994. The response of seedlings of two dipterocarp species to nutrient additions and ectomycorrhizal infection. *Plant and Soil* 163: 299-306. DOI: 10.1007/BF00007979
- Lee, S.S. and Lim, K.L. 1989. Mycorrhizal infection and foliar phosphorus content of seedlings of three dipterocarp species growing in a selectively logged forest and a forest plantation. *Plant and Soil* 117: 237-241. DOI: 10.1007/BF02220717
- Lee, S.S., Alias, S.A., Jones, E.G.B., Zainuddin, N. and Chan, H.T. 2012. Checklist of fungi in Malaysia. Forest Research Institute, Kepong, Malaysia
- Lee, S.S., Patahayah, M., Chong, W.S. and Lapeyrie, F. 2008. Successful ectomycorrhizal inoculation of two dipterocarp species with a locally isolated fungus in Peninsular Malaysia. *Journal of Tropical Forest Science*: 237-247.

- Lee, S.S., Walting, R. and Turnbull, E. 2003. Diversity of Putative Ectomycorrhizal Fungi in Pasoh Forest Reserve In Okuda, T., Manokaran, N., Matsumoto, Y., Niiyama, K. Thomas, S.C. and Ashton, P.S. eds. *Pasoh: Ecology of a Lowland Rain Forest in Southeast Asia*: 35 –50. Springer-Verlag, Tokyo. DOI: 10.1007/978-4-431-67008-7\_11
- Lillieskov, E.A. and Bruns, T.D. 2005. Spore dispersal of a resupinate ectomycorrhizal fungus, *Tomentella sublilacina*, via soil foo webs. *Mycologia* 97 (4): 762-769. DOI: 10.3852/mycologia.97.4.762
- Lindahl, B. & Boberg, J. 2008. Distribution and function of litter basidiomycetes in coniferous forest. In: Boddy, L., Frankland, J.C. & van West, P. eds. *Ecology of Saprotrophic Basidiomycetes. British Mycological Society Symposia Series*: 183-196. Academic press/Elsevier, Amsterdam/Boston.
- Lindahl, B. D., Ihrmark, K., Boberg, J., Trumbore, S. E., Högberg, P., Stenlid, J. and Finlay, R. D. 2007. Spatial separation of litter decomposition and mycorrhizal nitrogen uptake in a boreal forest. *New Phytologist* 173: 611–620. DOI:10.1111/j.1469-8137.2006.01936.x
- Lindahl, B., Stenlid, J. and Finlay, R. 2001. Effects of resource availability on mycelial interactions and <sup>32</sup>P transfer between a saprotrophic and an ectomycorrhizal fungus in soil microcosms. *FEMS Microbiology Ecology* 38: 43-52. DOI: 10.1111/j.1574-6941.2001.tb00880.x
- Lindahl, B., Stenlid, J., Olsson, S. and Finlay, R. 1999. Translocation of <sup>32</sup>P between interacting mycelia of a wood-decomposing fungus and ectomycorrhizal fungi in microcosm systems. *New Phytologist*: 144183–144193. DOI: 10.1046/j.1469-8137.1999.00502.x
- Lindahl, B., Taylor, A.F.S., Finlay, R.D. 2002. Defining nutritional constraints on carbon cycling in boreal forests—towards a less ‘phytcentric’ perspective. *Plant and Soil* 242: 123–135. DOI: 10.1023/A:1019650226585
- Lindahl, B.D. and Tunlid, A. 2015. Ectomycorrhizal fungi—potential organic matter decomposers, yet not saprotrophs. *New Phytologist* 205(4): 1443-1447.
- Lindahl, B.D., Finlay, R.D. and Cairney, J.W. 2005. Enzymatic activities of mycelia in mycorrhizal fungal communities. *Mycology Series* 23: 331.
- Liu, K., Eastwood, R.J., Flynn, S., Turner, R.M. and Stuppy, W.H. 2008. Royal Botanic Gardens Kew. Seed Information Database (SID). Version 7.1. Available from: <http://data.kew.org/sid/> (August 2015)
- Lodge, D.J. 1992. Nutrient cycling by fungi in wet tropical forests. In Frankland, J.C., Whalley, A.J. and Watling, R. eds. *Aspects of tropical mycology*: 37-57. Cambridge: Cambridge University Press.
- Lodge, D.J. McDowell, W.H., Macy, J., Ward, S.K., Leisso, R, Claudio-Campos, K. and Kühnert, K. 2008. Chapter 11 Distribution and role of mat-forming saprobic basidiomycetes in a tropical forest. *British Mycological Society Symposia Series* 28: 197-209. DOI: 10.1016/S0275-0287(08)80013-6
- Lodge, D.J. 1993. Nutrient cycling by fungi in wet tropical forests. In *British Mycological Society Symposium Series* 19: 37-37. Cambridge University Press.

- Lodge, D.J., McDowell, W.H. and McSwiney. 1994. The importance of nutrient pulses in tropical forests. *Tree* 9(1): 384-387. DOI : 10.1016/0169-5347(94)90060-4
- Manokaran, N. and Kochummen K. M., 1990. A reexamination of data on structure and floristic composition of hill and lowland dipterocarp forest in Peninsular Malaysia. *Malayan Nature Journal* 44: 61-75.
- Manokaran, N. and LaFrankie Jr, J.V. 1990. Stand structure of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science*: 14-24.
- Manokaran, N., LaFrankie, J.V. and Ismail, R. 1991. Structure and composition of the dipterocarpaceae in a lowland rain forest in Peninsular Malaysia. *Agris Conference* 41.
- Manokaran, N., LaFrankie, J.V., Kochummen, K.M., Quah, E.S. and Klahn, J. 1990. *Methodology for the fifty hectare research plot at Pasoh Forest Reserve. Kepong (Malaysia)*: Forest Research Institute Malaysia: 69. [Elektronik version].
- Manokaran, N., Quah, E. S., Ashton, P. S., LaFrankie, J. V., Noor, N. S. M., Ahmad, W. M. S. W., and Okuda, T. 2004. Tropical forest diversity and dynamism: Findings from a large-scale plot network. In Losos, E.C. and Leigh, E.G. eds. *Pasoh Forest Dynamics Plot, Peninsular Malaysia*: 585-598. Chicago University Press, Chicago.
- Massicotte, H.B., Peterson, R.L., Ackerley, C.A. and Ashford, A.E. 1987. Ontogeny of *Eucalyptus pilularis*-*Pisolithus tinctorius* ectomycorrhizae. II. Transmission electron microscopy. *Canadian journal of botany* 65(9): 1940-1947.
- May, R.M. 1973. Qualitative Stability in Model Ecosystems. *Ecology* 54 (3): 638-641. DOI: 10.2307/1935352
- McGuire, K.L. 2007. Common ectomycorrhizal Networks may maintain monodominance in a Tropical Rainforest. *Ecology* 88(3): 567-574. DOI: 10.1890/05-1173
- McGuire, Krista L. 2014. The contribution of ectomycorrhizal fungal feedbacks to the maintenance of tropical monodominant rain forests. *Ectomycorrhizal Symbioses in Tropical and Neotropical Forests*: 185.
- Miller, R.M. and Jastrow, J.D. 2000. Mycorrhizal fungi influence soil structure. In Kapulnik, Y. and Douds, D.D., Jr. eds. *Arbuscular Mycorrhizas: Physiology and Function*: 3-18. Springer, Netherlands. DOI : 10.1007/978-94-017-0776-3\_1
- Molina, R., Massicotte, H. and Trappe, J.M. 1992. Specificity phenomena in mycorrhizal symbioses: community-ecological consequences and practical implications. *Mycorrhizal functioning: an integrative plant-fungal process* 357: 423.
- Moore, J.A.M., Jiang, J., Post, W.M. and Classen, A.T. 2015. Decomposition by ectomycorrhizal fungi alters soil carbon storage in a simulation model. *Ecosphere* 6(3): 1-16. DOI: 10.1890/ES14-00301.1
- Morin, C., Samson, J. and Dessureault, M. 1999. Protection of black spruce seedlings against *Cylindrocladium* root rot with ectomycorrhizal fungi. *Canadian Journal of Botany* 77(1): 169-174. DOI: 10.1139/b99-025

- Morselt, A.F., Smits, W.T. and Limonard, T. 1986. Histochemical demonstration of heavy metal tolerance in ectomycorrhizal fungi. *Plant and soil* 96(3): 417-420. DOI: 10.1007/BF02375146
- Nara, K. 2006. Ectomycorrhizal networks and seedling establishment during early primary succession. *New Phytologist* 169(1): 169-178. DOI: 10.1111/j.1469-8137.2005.01545.x
- Näsholm, T., Ekblad, A., Nordin, A., Giesler, R., Högberg, M. and Högberg, P. 1998. Boreal forest plants take up organic nitrogen. *Nature* 392(6679): 914-916. DOI: 10.1038/31921
- Newbery, D. M., Alexander, I. J. and Rother, J. A. 2000. Does proximity to conspecific adults influence the establishment of ectomycorrhizal trees in rain forest? *New Phytologist* 147: 401-409. DOI: 10.1046/j.1469-8137.2000.00698.x
- Newbery, D.M. 2005. Ectomycorrhizas and mast fruiting in trees: linked by climate-driven tree resources?. *New phytologist* 167(2): 324-326. DOI: 10.1111/j.1469-8137.2005.01468.x
- Nilsson, R.N., Ryberg, M., Kristiansson, E., Abarenkov, K., Larsson, K-H. and Kõljalg, U. 2006. Taxonomic Reliability of DNA Sequences in Public Sequence Databases: A Fungal Perspective. Fairhead C, eds. *PLoS ONE* 1 (1): e59. DOI:10.1371/journal.pone.0000059.
- O'Brien, H.E., Parrent, J.L., Jackson, J.A., Moncalvo, J.M., Vilgalys, R. 2005. Fungal community analysis by large-scale sequencing of environmental samples. *Applied and Environmental Microbiology* 71: 5544-5550. DOI: 10.1128/aem.71.9.5544-5550.2005
- Pearson, W.R. and Miller, W., 1992. Dynamic programming algorithms for biological sequence comparison. *Methods in enzymology* 210: 575-601.
- Peay, K.G., Garbelotto, M. and Bruns, T.D. 2010. Evidence of dispersal limitation in soil microorganisms: isolation reduces species richness on mycorrhizal tree islands. *Ecology* 91(12): 3631-3640. DOI: 10.1890/09-2237.1
- Peh, K.S., Lewis, S.L., and Lloyd, J. 2011. Mechanisms of monodominance in diverse tropical tree-dominated systems. *Journal of Ecology* 99: 891-898. DOI: 10.1111/j.1365-2745.2011.01827.x
- Peh, K.S-H., Sonké, B., Séné, O., Djuikouo, M-N.K., Nguembou, C.K., Taedoumg, H., eBegne, S.K. and Lewis, S.L. 2014. Mixed-Forest Species Establishment in a Monodominant Forest in Central Africa: Implications for Tropical Forest Invasibility. *PLoS ONE* 9(5): e97585. DOI: 10.1371/journal.pone.0097585
- Perry, D.A., Bell, T. and Amaranthus, M.P. 1992. Mycorrhizal fungi in mixed-species forests and other tales of positive feedback, redundancy and stability. *The ecology of mixed species stands of trees*: 151-179. Blackwell, Oxford.
- Petersen, R.H. 2000. New Species of *Lentaria* (Fungi: Aphyllophorales): redescription and mating systems of *L. surculus* and *L. byssiseda*. *Revista de biología tropical*, 48(2-3): 555-567.
- Peterson, R. L., and Bonfante, P. 1994. Comparative structure of vesicular-arbuscular mycorrhizas and ectomycorrhizas. *Plant and Soil* 159: 79-88. DOI: 10.1007/BF00000097

- Plett, J.M. and Martin, F. 2011. Blurred boundaries: lifestyle lessons from ectomycorrhizal fungal genomes. *Trends in Genetics* 27(1): 14-22. DOI: 10.1016/j.tig.2010.10.005
- Primack, R. and Corlett, R. 2005. Tropical Rain-Forests: An Ecological and Biogeographical Comparison. Blackwell Publication Malden, USA.
- R Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org/>
- Read, D.J. 1997. Mycorrhizal fungi: the ties that bind. *Nature* 388: 517-518
- Read, D.J. and Perez-Moreno, J. 2003. Mycorrhizas and nutrient cycling in ecosystems—a journey towards relevance? *New Phytologist* 157: 475–492. DOI: 10.1046/j.1469-8137.2003.00704.x
- Richards, P.W. 1996. The Tropical Rain Forest, 2nd edn, Cambridge University Press, Cambridge.
- Rineau, F. and Courty P.E. 2011. Secreted enzymatic activities of ectomycorrhizal fungi as a case study of functional diversity and functional redundancy. *Annals of Forest Science* (68): 69–80. DOI: 10.1007/s13595-010-0008-4
- Robbinson, D. and Fitter, A. 1999. The magnitude and control of carbon transfer between plants linked by a common mycorrhizal network. *Journal of Experimental Botany* 50(330): 9-13. DOI: 10.1093/jxb/50.330.9
- Sagara, N. 1995. Association of ectomycorrhizal fungi with decomposed animal wastes in forest habitats: a cleaning symbiosis? *Canadian Journal of Botany* 73(1): 1423-1433. DOI: 10.1139/b95-406
- Sanmee, R., Dell, B., Lumyong, P., Izumori, K. and Lumyong, S. 2003. Nutritive value of popular wild edible mushrooms from northern Thailand. *Food Chemistry* 82: 527-532. DOI: 10.1016/S0308-8146(02)00595-2
- Sasaki, S., and T. Mori. 1981. Growth responses of dipterocarp seedlings to light. *Malaysian Forester* 44(2/3): 319-345.
- Schickmann, S., Urban, A., Kräutler, K., Nopp-Mayr, U. and Hackländer, K. 2012. The interrelationship of mycophagous small mammals and ectomycorrhizal fungi in primeval, disturbed and managed Central European mountainous forests. *Oecologia*, 170(2): 395-409. DOI: 10.1007/s00442-012-2303-2
- Schützendübel, A. and Polle, A. 2002. Plant responses to abiotic stresses: heavy metal-induced oxidative stress and protection by mycorrhization. *Journal of Experimental Botany* 53(372): 1351-1365. DOI: 10.1093/jexbot/53.372.1351
- Seidler, T.G. and Plotkin, J.B. 2006. Seed dispersal and spatial pattern in tropical trees. *PLoS Biol* 4(11): e344. DOI: 10.1371/journal.pbio.0040344
- Silvertown, J. 2004. Plant coexistence and the niche. *Trends in Ecology & Evolution* 19(11): 605-611. DOI: 10.1016/j.tree.2004.09.003
- Simard, S.W., Perry, D.A., Jones, M.D., Myrold, D.D., Durall, D.M. and Molina, R. 1997. Net transfer of carbon between ectomycorrhizal tree species in the field. *Nature* 388(6642): 579-582.
- Sinsabaugh, R.L. 2010. Phenol oxidase, peroxidase and organic matter dynamics of soil. *Soil Biology and Biochemistry* 42(3): 391-404. DOI: 10.1016/j.soilbio.2009.10.014

- Smith J.D. 1957. Fungi and turf diseases. 7. Fairy rings. *Journal of the Sports Turf Research Institute* 33: 324-52.
- Smith, M.E., Henkel, T.W., Catherine Aime, M., Fremier, A.K. and Vilgalys, R. 2011. Ectomycorrhizal fungal diversity and community structure on three co-occurring leguminous canopy tree species in a Neo tropical rainforest. *New Phytologist* 192: 699-712. DOI: 10.1111/j.1469-8137.2011.03844.x
- Smith, S.E. and Read, D.J. 1997. The role of mycorrhizas in ecosystems. Academic Press, London.
- Smith, S.S.E. 1980. Mycorrhizas of autotrophic higher plants. *Biological Reviews* 55: 475–510. DOI: 10.1111/j.1469-185X.1980.tb00701.x
- Smits, M. M., Bonneville, S., Benning, L. G., Banwart, S. A. and Leake, J. R. 2012. Plant-driven weathering of apatite – the role of an ectomycorrhizal fungus. *Geobiology* 10: 445–456. DOI: 10.1111/j.1472-4669.2012.00331.x
- Smits, W. T. M. 1992. Mycorrhizal studies in dipterocarp forests in Indonesia.. In Read, D. J., Lewis, D. H., Fitter, A. H. and Alexander, I. J. eds. *Mycorrhizas in Ecosystems*: 283–292. CAB International, Wallingford.
- Smits, W.T.M. 1994. Dipterocarpaceae: mycorrhizae and regeneration. Tropenbos series 9, Wageningen, The Netherlands 243: 149-159. Springer-Verlag, Tokyo.
- Steffen, K.T., Hofrichter, M. and Hatakka, A. 2002. Purification and characterization of manganese peroxidases from the litter-decomposing basidiomycetes *Agrocybe praecox* and *Stropharia coronilla*. *Enzyme and Microbial Technology* 30(4): 550-555.
- Stoll, P. and Newbery, D.M. 2005. Evidence of species-specific neighborhood effects in the Dipterocarpaceae of a Bornean rain forest. *Ecology* 86(11): 3048-3062. DOI: 10.1890/04-1540
- Talbot, J.M., Bruns, T.D., Smith, D.P., Branco, S., Glassman, S.I., Erlandson, S., Vilgalys, R., and Peay, K.G. 2013. Independent roles of ectomycorrhizal and saprotrophic communities in soil organic matter decomposition. *Biology and Biochemistry* (57): 282-291. DOI : 10.1016/j.soilbio.2012.10.004
- Tedersoo, L., Suvi, T., Beaver, K. and Kõljalg, U. 2007. Ectomycorrhizal fungi of the Seychelles: diversity patterns and host shifts from the native *Vateriopsis seychellarum* (Dipterocarpaceae) and *Intsia bijuga* (Caesalpinaceae) to the introduced *Eucalyptus robusta* (Myrtaceae), but not *Pinus caribea* (Pinaceae). *New Phytologist* 175: 321–333. DOI:10.1111/j.1469-8137.2007.02104.x
- Teste, F.P. and Simard, S.W. 2008. Mycorrhizal networks and distance from mature trees alter patterns of competition and facilitation in dry Douglas-fir forests. *Oecologia* 158(2): 193-203. DOI: 10.1007/s00442-008-1136-5
- Thind, K.S. and Sharda, R.M. 1985. Genus Ramaria in the eastern Himalaya: Subgenus Laeticolora—I. *Proceedings: Plant Sciences* 95(4): 271-281. DOI: 10.1007/BF03053262
- Tibbett, M. and Sanders, F.E. 2002. Ectomycorrhizal symbiosis can enhance plant nutrition through improved access to discrete organic nutrient patches of high resource quality. *Annals of Botany* 89(6): 783-789. DOI: 10.1093/aob/mcf129

- Tlalka, M., Bebber, D., Darrah, P.R. and Watkinson, S.C. 2008. Mycelial networks: nutrient uptake, translocation and role in ecosystems. In *British Mycological Society Symposia Series* 28: 43-62. Academic Press. DOI: 10.1016/S0275-0287(08)80005-7
- Tompsett, P.B. 1994. Capture of genetic resources by collection and storage of seed: a physiological approach. In *ITE Symposium* 29: 61-61. Institute Of Terrestrial Ecology.
- Tompsett, P.B. and Pritchard, H.W. 1998. The Effect of Chilling and Moisture Status on the Germination, Desiccation Tolerance and Longevity of *Aesculus hippocastanum* L. Seed. *Annals of Botany* 82(2): 249-261. DOI: 10.1006/anbo.1998.0676
- Torti, S.D. and Coley, P.D. 1999. Tropical Monodominance: A Preliminary Test of Ectomycorrhizal Hypothesis. *Biotropica* 31 (2): 220-228. DOI: 10.1111/j.1744-7429.1999.tb00134.x
- Torti, S.D., Coley P.D. and Janos, D.P. 1997. Vesicular-arbuscular mycorrhizae in two tropical monodominant species. *Journal of Tropical Ecology* 13: 623-629. DOI : 10.1017/S0266467400010762
- Torti, S.D., Coley, P.D. and Kursar, T.A. 2001. Causes and consequences of monodominance in tropical lowland forests. *The American Naturalist* 157(2): 141-153.
- Trappe, M.J., Cromack, K., Caldwell, B.A., Griffiths, R.P. and Trappe, J.M. 2012. Diversity of mat-forming fungi in relation to soil properties, disturbance, and forest ecotype at Crater Lake National Park, Oregon, USA. *Diversity* 4(2): 196-223. DOI: 10.3390/d4020196
- Turnbull, M.H., Goodall, R. and Stewart, G.R. 1995. The impact of mycorrhizal colonization upon nitrogen source utilization and metabolism in seedlings of *Eucalyptus grandis* Hill ex Maiden and *Eucalyptus maculata* Hook. *Plant, Cell & Environment* 18(12): 1386-1394. DOI: 10.1111/j.1365-3040.1995.tb00199.x
- Unestam, T. 1991. Water repellency, mat formation, and leaf-stimulated growth of some ectomycorrhizal fungi. *Mycorrhiza* 1: 13-20. DOI: 10.1007/BF00205897
- Van der Heijden, M.G. 2010. Mycorrhizal fungi reduce nutrient loss from model grassland ecosystems. *Ecology* 91: 1163-1171. DOI: 10.1890/09-0336.1
- Vilgays, R. 2003. Taxonomic misidentification in public DNA databases. *New Phytologist* 160: 4-5. DOI: 10.1046/j.1469-8137.2003.00894.x
- Walters, M.B. and Reich, P.B. 2000. Seed size, nitrogen supply, and growth rate affect tree seedling survival in deep shade. *Ecology* 81(7): 1887-1901. DOI: 10.1890/0012-9658(2000)081[1887:SSNSAG]2.0.CO;2
- Watkins, N.K., Fitter, A.H., Graves, J.D. and Robbinson, D. 1996. Carbon transfer between C3 and C4 plants linked by a common mycorrhizal network, quantified using stable carbon isotopes. *Soil Biology and Biochemistry* 28 (4-5): 471-477. DOI: 10.1016/0038-0717(95)00189-1
- Whipps, J.M. 2004. Prospects and limitations for mycorrhizas in biocontrol of root pathogens. *Canadian Journal of Botany* 82(8): 1198-1227. DOI: 10.1139/b04-082
- Whitmore, T.C. 1984. A vegetation map of Malesia at scale 1: 5 million. *Journal of Biogeography*: 461-471. DOI: 10.2307/2844792

- Wiegand T., and K. A. Moloney. 2014. A handbook of spatial point pattern analysis in ecology. Chapman and Hall/CRC press, Boca Raton, FL.
- Wiegand, T. and Moloney, K.A. 2004. Rings, circles, and null models for point pattern analysis in ecology. *Oikos* 104: 209-229. DOI: 10.1111/j.0030-1299.2004.12497.x
- Wright, J.S. 2002. Plant diversity in tropical forests: a review of mechanisms of species coexistence. *Oecologia* 130(1): 1-14. DOI: 10.1007/s004420100809
- Wright, S.J., Muller-Landau, H.C., Condit, R. and Hubbell, P. 2003. Gap-dependent recruitment, realized vital rates, and size distribution of tropical trees. *Ecology* 84 (12): 3174-3185. DOI: 10.1890/02-0038
- Wu, T., Sharda, J.N. and Koide, R.T. 2003. Exploring interactions between saprotrophic microbes and ectomycorrhizal fungi using a protein-tannin complex as an N source by red pine (*Pinus resinosa*). *New Phytologist* 159: 131-139. DOI: 10.1046/j.1469-8137.2003.00800.x
- Yang, J.C. and Insam, H. 1991. Microbial biomass and relative contributions of bacteria and fungi in soil beneath tropical rain forest, Hainan Island, China. *Journal of Tropical Ecology* 7(03): 385-393. DOI: 10.1017/S0266467400005678
- Yazid, M.S., Lee, S.S. and Laperriere, F. 1994. Growth stimulation of Hopeaspp. (Dipterocarpaceae) seedlings following inoculation with an exotic strain of *Pisolithus tinctorius*. *Forest Ecology and Management* 67: 339-343. DOI: 10.1016/0378-1127(94)90028-0
- Yun, W. and Hall, I.R. 2004. Edible ectomycorrhizal mushrooms: challenges and achievements. *Canadian Journal of Botany* 82 (8): 1063-1073. DOI: 10.1139/b04-051
- Zeng, R.S. and Malik, A.U. 2006. Selected Ectomycorrhizal fungi of black spruce (*Picea mariana*) can detoxify phenolic compounds of *Kalmia angustifolia*. *Journal of Chemical Ecology* 32: 1473-1489. DOI: 10.1007/s10886-006-9063-6

## BIODATA OF STUDENT

Riri Rimbun Anggih Chaidir was born on August 10, 1988, in Pintu Padang, Sumatera Utara, Indonesia. She received her early education in SDN 1101466 Perumnas Pijor Koling, SMP N 7 Medan and SMAN 4 Medan, before pursuing her Bachelor degree in Universiti Kebangsaan Malaysia (UKM) at Faculty of Science and Technology, allowing her to graduate as Bachelor of Science in Microbiology in 2010. She furthered her study in Universiti Putra Malaysia for Master of Science, focusing on Forest Disturbance Impact Evaluation in Institute of Tropical Forestry and Forest Product (INTROP).





**UNIVERSITI PUTRA MALAYSIA**

**STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT**

**ACADEMIC SESSION :** \_\_\_\_\_

**TITLE OF THESIS / PROJECT REPORT :**

SPATIAL DISTRIBUTION OF ECTOMYCORRHIZAL AND SAPROPHYTIC FUNGI IN  
RELATION WITH *Shorea leprosula* Miq. SEEDLING SURVIVAL IN DIPTEROCARP FOREST

**NAME OF STUDENT :** RIRI RIMBUN ANGGIH CHAIDIR

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

\*Please tick (✓)

**CONFIDENTIAL**

(Contain confidential information under Official Secret Act 1972).

**RESTRICTED**

(Contains restricted information as specified by the organization/institution where research was done).

**OPEN ACCESS**

I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

**PATENT**

Embargo from \_\_\_\_\_ until \_\_\_\_\_  
(date) (date)

**Approved by:**

\_\_\_\_\_  
(Signature of Student)  
New IC No/ Passport No.:  
A 3488450  
Date : 13<sup>th</sup> March 2017

\_\_\_\_\_  
(Signature of Chairman of Supervisory Committee)  
Name:  
Date :

**[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted. ]**