

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Optimal Forest Management for  
Carbon Sequestration and Biodiversity Maintenance**

A thesis presented in fulfilment of the requirements for the degree of

**Doctor of Philosophy**

in

**Economics**

at Massey University, Turitea,  
New Zealand

**Thi Hong Nhung Nghiem**

2011

## ABSTRACT

Managing planted forests for carbon sequestration and biodiversity maintenance has become increasingly important in times of rapid climate change and the loss of biodiversity worldwide. The objectives of this study are to find out private and socially optimal management strategies for planted forests, and suggest an appropriate policy for promoting multiple-use forests.

The research attempts: (1) to identify the harvesting strategies of forest stands that can maximise the benefits from timber production and carbon sequestration; (2) to identify the patterns that can balance economic gain and biodiversity maintenance; (3) to examine the actual management strategies and biodiversity conservation attitudes of forest owners; and (4) to recommend policy tools that can be used to align private with socially optimal decisions.

The Faustmann model is extended to include carbon sequestration, biodiversity conservation, multiple forest stands and spatial arrangements among forest stands. The Safe Minimum Standard Approach is employed to model biodiversity conservation. The number of birds is used as a biodiversity indicator. A direct search algorithm is used to determine optimal sets of harvesting strategies. The models are applied to planted forests in Yen Bai province, Vietnam. To get primary data, 291 household forest owners and 4 state enterprises, growing *Eucalyptus urophylla* and *Acacia mangium* were surveyed.

The results show that the actual cutting ages are 5 and 7 years for household and enterprise forests, respectively. Both the optimal timber and carbon rotation ages are between 9 and 11 years for two species. The value of carbon uptake makes the optimal rotation age slightly shorter. The incorporation of spatial arrangements has little impact on the optimal rotation age, but significantly increases the net present value. The inclusion of biodiversity conservation lengthens the rotation age and significantly reduces the profitability of forest owners. Policy implications are that payment for carbon sequestration services of planted forests in Vietnam is feasible. Merging small forest stands of several forest households should be encouraged. Direct payments are an appropriate policy tool to encourage household forest owners to lengthen rotation ages in order to enhance biodiversity.

## ACKNOWLEDGEMENTS

I would like to express my sincere thanks to a number of people without whom this thesis would not have been possible. Firstly, I would like to thank my supervisor, Professor Anton Meister, for his excellent guidance and encouragement through out this research. Professor Anton's valuable suggestions, corrections, and prompt responses have contributed much to the completion of this thesis. I would also like to extend my deep gratitude to my co-supervisor, Dr. Brendan Moyle, for his valuable guidances, understanding, and support for my study.

I am indebted to the Vietnamese Government to provide me a scholarship to study my PhD. My grateful thanks also go to the Economy and Environmental Program for South East Asia (EEPSEA) for providing me a fellowship to implement the thesis fieldwork, particularly to Professor Nancy Olewiler (Simon Fraser University), Associate Prof. Ted Horbulyk (University of Calgary), and Dr. Herminia Francisco (EEPSEA Director) for their thorough criticisms on my research proposal and reports at EEPSEA.

I would like to express my gratitude to the organizers of the following conferences for providing me scholarship and/or travel grants: the EEPSEA 31<sup>st</sup> Biannual Workshop, 2009, Hanoi, Vietnam; International Scientific Congress "Climate change: Global risks, Challenges and Decisions", 2009, Copenhagen, Denmark; EEPSEA 29<sup>th</sup> Biannual Workshop, 2008, Nonthaburi, Thailand; and Environmental and Resource Economics Early-Career Researcher Workshop, 2007, Charles Sturt University, Australia. I also highly appreciate the comments from the discussants and participants at these conferences and at the 17<sup>th</sup> EAERE Annual Conference 2009, Amsterdam, the Netherlands.

Special thanks also go to Professor Martin Young for providing me financial support for meeting up with my co-supervisor and for an international conference; and other academic and administrative staff of the School of Economics and Finance, particularly Ms. Ha Lien Ton and Ms. Sue Edwards. I would also like to thank the Student Learning Centre for their help with improving the written language in my thesis, and to the International Student Office for their support.

I would like to thank Dr. Nguyen Nghia Bien, Director of Forestry Department, Vietnam Ministry of Agriculture and Rural Development, who has encouraged me and has given many creative ideas on improving the research. I would also like to extend my thanks to my colleagues at Vietnam Forestry University, particularly Department of Economics, for their patience, constructive suggestions, and excellent field assistance. Thanks to Mr. Kieu Tu Giang, Head of Forestry Department, and people in Yen Bai province who have been very cooperative and enthusiastically attending interviews.

Finally, many thanks to my husband and my son for their understanding, sharing, and inspiration. Thanks to my mother who has encouraged me and taken care of my lovely son. My special thanks are also extended to my sisters, and other members of my extended family for their patience, support, and encouragement.

## **LIST OF RESEARCH OUTPUTS DURING THE PHD STUDY PERIOD**

EEPSEA 31<sup>st</sup> Biannual Workshop. Presenting final research report titled *Optimal Forest Management for Carbon Sequestration: A Case Study of Household Forest Owner and State Enterprises*, 16-19<sup>th</sup> November 2009, Hanoi, Vietnam.

The 17<sup>th</sup> EAERE Annual Conference. Presenting the paper titled *The opportunity cost of biodiversity in planted forests: A Case Study of Pinus Radiata in New Zealand*, 24-27<sup>th</sup> June, 2009, Amsterdam, the Netherlands.

International Scientific Congress “Climate change: Global risks, Challenges and Decisions”. Presenting the paper titled *Optimal Forest Management for Carbon Sequestration: A Case Study in Yen Bai Province, Vietnam*, 10-12<sup>th</sup> March 2009, Copenhagen, Denmark.

EEPSEA 29<sup>th</sup> Biannual Workshop. Presenting research proposal titled *Optimal Forest Management for Carbon Sequestration: A Case Study of Eucalyptus Urophylla and Acacia Mangium in Yen Bai Province, Vietnam*, 5-8<sup>th</sup> May 2008, Nonthaburi, Thailand.

Environmental and Resource Economics Early-Career Researcher Workshop. Presenting the paper entitled *Optimal Forest Management for Balancing Economic Gain and Biodiversity over Multiple Age-classes and Spatial Interdependence*, 12-13<sup>th</sup> November 2007, Charles Sturt University, Australia.

# TABLE OF CONTENTS

ABSTRACT .....	I
ACKNOWLEDGEMENTS .....	III
LIST OF RESEARCH DURING THE PHD STUDY PERIOD .....	V
LIST OF TABLES .....	X
LIST OF FIGURES .....	XII
LIST OF ABBREVIATIONS AND SYMBOLS .....	XIII
<b>1. CHAPTER ONE. INTRODUCTION.....</b>	<b>1</b>
1.1 INTRODUCTION.....	1
1.2 BACKGROUND AND PROBLEM STATEMENTS.....	2
1.2.1 <i>The Kyoto Protocol and the Vietnamese Government policies.....</i>	<i>2</i>
1.2.2 <i>The Convention on Biological Diversity.....</i>	<i>4</i>
1.2.3 <i>Biodiversity in Vietnam.....</i>	<i>5</i>
1.2.4 <i>Planted forests in Vietnam.....</i>	<i>5</i>
1.3 THE STUDY AREA .....	8
1.3.1 <i>General conditions.....</i>	<i>8</i>
1.3.2 <i>The forest resource and legal framework.....</i>	<i>9</i>
1.3.3 <i>Market conditions.....</i>	<i>11</i>
1.4 RESEARCH OBJECTIVES.....	13
1.4.1 <i>General objectives.....</i>	<i>13</i>
1.4.2 <i>Specific objectives.....</i>	<i>13</i>
1.5 RESEARCH QUESTIONS.....	14
1.5.1 <i>Optimal forest management for timber production and carbon sequestration.....</i>	<i>14</i>
1.5.2 <i>Optimal forest management for biodiversity conservation.....</i>	<i>15</i>
1.5.3 <i>Policy tools and the optimal level of direct payments.....</i>	<i>16</i>
1.6 CONTRIBUTIONS.....	16
1.7 THE STRUCTURE OF THE THESIS .....	18



<b>2. CHAPTER TWO. LITERATURE REVIEW.....</b>	<b>19</b>
2.1 INTRODUCTION.....	19
2.2 OPTIMAL FOREST MANAGEMENT.....	20
2.2.1 <i>Optimal forest management when only timber has market value</i> .....	20
2.2.2 <i>Optimal forest management including amenity values and carbon sequestration</i> .....	22
2.2.3 <i>Optimal forest management with biodiversity maintenance</i> .....	26
2.2.4 <i>Optimal forest management under uncertainty</i> .....	29
2.2.5 <i>Optimal forest subsidy for promoting biodiversity</i> .....	32
2.3 ENHANCING BIODIVERSITY IN PLANTED FORESTS.....	33
2.3.1 <i>Definition of biodiversity and its importance</i> .....	33
2.3.2 <i>Biodiversity measurement</i> .....	37
2.3.3 <i>Biodiversity valuation</i> .....	39
2.3.4 <i>Forest management and biodiversity</i> .....	43
2.4 PUBLIC POLICIES FOR FOREST MANAGEMENT.....	45
2.4.1 <i>Definition and classification of public policies</i> .....	46
2.4.2 <i>Regulations</i> .....	47
2.4.3 <i>Education</i> .....	48
2.4.4 <i>Subsidies and taxes</i> .....	49
2.4.5 <i>Direct payments</i> .....	50
2.4.6 <i>Payment for environmental services</i> .....	53
2.4.7 <i>Forest certification</i> .....	54
2.4.8 <i>Biodiversity offsets</i> .....	55
2.4.9 <i>Integrated conservation-development projects</i> .....	56
2.4.10 <i>Other policy tools</i> .....	58
2.5 SUMMARY .....	59
<b>3. CHAPTER THREE. METHODOLOGY .....</b>	<b>61</b>
3.1 INTRODUCTION.....	61
3.2 SET UP FOR THE BIODIVERSITY MODEL.....	61
3.2.1 <i>The safe minimum standard approach</i> .....	61
3.2.2 <i>The selection of taxa as a biodiversity indicator</i> .....	67
3.2.3 <i>The calculation of population size</i> .....	71

3.2.4	<i>The minimum viable population (MVP)</i> .....	72
3.3	THE OPTIMIZATION MODELS.....	74
3.3.1	<i>The timber optimization model</i> .....	74
3.3.2	<i>The carbon optimization model</i> .....	76
3.3.3	<i>The biodiversity optimization model</i> .....	77
3.3.4	<i>The optimal subsidy model</i> .....	80
3.4	THE OPTIMIZATION METHOD AND DATA .....	81
3.4.1	<i>The optimization method</i> .....	81
3.4.2	<i>Model data</i> .....	84
3.5	GROWTH AND SEQUESTRATION FUNCTIONS AND BIRD POPULATION .....	86
3.5.1	<i>Timber growth function</i> .....	86
3.5.2	<i>Carbon sequestration function</i> .....	87
3.5.3	<i>Bird abundance function</i> .....	89
3.6	THE SURVEY .....	92
3.6.1	<i>Questionnaire development</i> .....	92
3.6.2	<i>Survey implementation</i> .....	93
3.6.3	<i>Data analysis</i> .....	95
<b>4.</b>	<b>CHAPTER FOUR. RESULTS AND DISCUSSION.....</b>	<b>98</b>
4.1	INTRODUCTION.....	98
4.2	THE SURVEY .....	98
4.2.1	<i>Descriptive data</i> .....	99
4.2.2	<i>Planting cost and timber price</i> .....	101
4.2.3	<i>Forest management for timber production and carbon sequestration</i> <i>106</i>	
4.2.4	<i>Payment for carbon sequestration</i> .....	108
4.2.5	<i>Biodiversity conservation attitudes</i> .....	111
4.3	TIMBER AND CARBON OPTIMIZATION MODELS .....	113
4.3.1	<i>The optimal rotation age at stand level</i> .....	114
4.3.2	<i>The optimal rotation age at forest level</i> .....	119
4.3.3	<i>Sensitivity analysis to carbon price</i> .....	123
4.3.4	<i>Sensitivity analysis to carbon payment scheme</i> .....	126

4.3.5	<i>Sensitivity analysis for a changing planting cost subsidy</i> .....	127
4.3.6	<i>Sensitivity analysis to timber price</i> .....	129
4.3.7	<i>Sensitivity analysis to carbon sequestration functions</i> .....	131
4.3.8	<i>Sensitivity analysis to economies of planting scale</i> .....	132
4.4	<b>BIODIVERSITY OPTIMIZATION MODEL</b> .....	134
4.4.1	<i>The optimal rotation age</i> .....	135
4.4.2	<i>The role of longer rotations to the enhancement of biodiversity</i> ....	137
4.4.3	<i>Sensitivity analysis to the minimum viable population</i> .....	139
4.4.4	<i>Sensitivity analysis to the discount rate</i> .....	140
4.4.5	<i>Sensitivity analysis to the carbon price</i> .....	142
4.4.6	<i>Sensitivity analysis to the timber price</i> .....	143
4.5	<b>POLICY ANALYSIS</b> .....	146
4.5.1	<i>The optimal levels of direct payments</i> .....	146
4.5.2	<i>The analysis of the forest policy tools</i> .....	148
4.5.3	<i>The analysis of direct payments</i> .....	151
<b>5.</b>	<b>CHAPTER FIVE. SUMMARY AND CONCLUSIONS</b> .....	<b>154</b>
5.1	<b>INTRODUCTION</b> .....	154
5.2	<b>SUMMARY OF THE STUDY</b> .....	154
5.2.1	<i>Overview of the problem</i> .....	154
5.2.2	<i>Purpose statement</i> .....	155
5.2.3	<i>Review of the methodology</i> .....	156
5.2.4	<i>Major findings</i> .....	156
5.3	<b>CONCLUSIONS</b> .....	158
5.3.1	<i>Policy implications</i> .....	158
5.3.2	<i>Limitations</i> .....	160
5.3.3	<i>Recommendation for further research</i> .....	161
	<b>APPENDICES</b> .....	<b>162</b>
	APPENDIX A ANNUAL INCREMENT OF TIMBER GROWTH .....	162
	APPENDIX B QUESTIONNAIRES .....	164
	APPENDIX C GAMS CODING .....	180
	<b>REFERENCES</b> .....	<b>190</b>

## LIST OF TABLES

Table 3.1 Matrix of losses (Bishop) .....	63
Table 3.2 Matrix of losses (Ready and Bishop) .....	65
Table 3.3 An example to show how the model comes up with the same minimum number of birds by using the indicator $S_{Bt}$ .....	79
Table 3.4 Total abundance of all birds according to vertical height above ground .....	90
Table 3.5 Total abundance of birds at different stand ages (transferring from heights of trees) .....	90
Table 3.6 Location and sample size .....	95
Table 4.1 General information on the household forest owners .....	99
Table 4.2 Production information on the household forest owners .....	100
Table 4.3 Inflation rate in Vietnam .....	102
Table 4.4 Planting costs.....	102
Table 4.5 Timber price and revenue in 2007.....	103
Table 4.6 Stand level rotation ages for timber only and carbon values for <i>Eucalyptus urophylla</i> in forest households and enterprises .....	115
Table 4.7 Stand level rotation ages for timber only and carbon values for <i>Acacia mangium</i> in forest households and enterprises.....	116
Table 4.8 Case studies used for the forest level models for <i>Eucalyptus urophylla</i> .....	120
Table 4.9 Forest level rotation ages with timber only and carbon values for <i>Eucalyptus urophylla</i> .....	122
Table 4.10 Sensitivity analysis of the stand level carbon rotation age to carbon price for <i>Eucalyptus urophylla</i> in household and enterprise forests .....	124

Table 4.11 Sensitivity analysis of Faustmann rotation age to carbon price for <i>Acacia mangium</i> in forest households and enterprises.....	125
Table 4.12 The carbon rotation age at stand level with carbon payment scheme	126
Table 4.13 Sensitivity analysis of the carbon rotation age at stand level with the planting cost subsidy for <i>Eucalyptus urophylla</i> .....	127
Table 4.14 Sensitivity analysis of Faustmann carbon rotation age with the planting cost subsidy for <i>Acacia mangium</i> .....	128
Table 4.15 Sensitivity to carbon sequestration function at stand level for <i>Eucalyptus urophylla</i> .....	132
Table 4.16 Sensitivity of the timber optimal rotation to $\lambda$ at forest level for <i>Eucalyptus urophylla</i> .....	133
Table 4.17 The optimal results of all cases at an 8% discount rate and the 50 MVP for <i>Eucalyptus urophylla</i> .....	135
Table 4.18 Percentage of different forest stand types in the total forest area over a 50 year planning horizon.....	138
Table 4.19 Sensitivity analysis of the biodiversity rotation age to the MVP.....	139
Table 4.20 Sensitivity analysis of the biodiversity rotation age to the discount rate (MVP=50) .....	141
Table 4.21 Sensitivity analysis of the biodiversity rotation age to timber price.	145
Table 4.22 The optimal annual direct payments required to equate private and social rotation ages .....	147

## LIST OF FIGURES

Figure 1.1 Map of Yen Bai province.....	8
Figure 1.2 Proportion of forest land ownership in Yen Bai province .....	9
Figure 3.1 Graphical representation of the direct search algorithm .....	83
Figure 3.2 The bird abundance and age of stand.....	91
Figure 3.3 The function for bird abundance and age of stand: $S_{BT}=22.215e^{0.1421x}$ .....	92
Figure 4.1 Planting costs for <i>Eucalyptus urophylla</i> .....	104
Figure 4.2 Planting costs for <i>Acacia mangium</i> .....	105
Figure 4.3 Sensitivity analysis of the carbon rotation age at a stand level to timber price when timber price is varied with timber size .....	130
Figure 4.4 Sensitivity analysis of the carbon NPV to timber price when timber price is varied with timber size.....	130
Figure 4.5 Sensitivity of the carbon optimal rotation to $\lambda$ at forest level for <i>Eucalyptus urophylla</i> .....	134
Figure 4.6 Sensitivity analysis of the biodiversity rotation age to carbon price .	143

## LIST OF ABBREVIATIONS AND SYMBOLS

CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CV	Contingent Valuation
EUR	Euro
FAO	Food and Agriculture Organization
GAMS	General Algebraic Modelling System
FAO	Food and Agriculture Organization
ha	Hectare
MARD	Ministry of Agriculture and Rural Development
MVP	Minimum Viable Population
NPV	Net Present Value
PES	Payment for Environmental Services
r	Discount Rate
SMS	Safe Minimum Standard
T	Optimal Rotation Age
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VND	Vietnam Dong