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 31st Biannual Workshop, 2009, Hanoi, Vietnam; International Scientific Congress "Climate change: Global risks, Challenges and Decisions", 2009, Copenhagen, Denmark; EEPSEA 29th 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 17th 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 31st Biannual Workshop. Presenting final research report titled *Optimal Forest Management for Carbon Sequestration: A Case Study of Household Forest Owner and State Enterprises,* 16-19th November 2009, Hanoi, Vietnam.

The 17th EAERE Annual Conference. Presenting the paper titled *The opportunity cost of biodiversity in planted forests: A Case Study of Pinus Radiata in New Zealand,* 24-27th 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,* 10-12th March 2009, Copenhagen, Denmark.

EEPSEA 29th 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,* 5-8th 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*, 12-13th 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
1. CHAPTER ONE. INTRODUCTION 1
1.1 INTRODUCTION 1
1.2 BACKGROUND AND PROBLEM STATEMENTS 2
1.2.1 The Kyoto Protocol and the Vietnamese Government policies 2
1.2.2 The Convention on Biological Diversity 4
1.2.3 Biodiversity in Vietnam 5
1.2.4 Planted forests in Vietnam 5
1.3 THE STUDY AREA 8
1.3.1 General conditions 8
1.3.2 The forest resource and legal framework 9
1.3.3 Market conditions 11
1.4 RESEARCH OBJECTIVES 13
1.4.1 General objectives 13
1.4.2 Specific objectives 13
1.5 RESEARCH QUESTIONS 14
1.5.1 Optimal forest management for timber production and carbon sequestration 14
1.5.2 Optimal forest management for biodiversity conservation 15
1.5.3 Policy tools and the optimal level of direct payments 16
1.6 CONTRIBUTIONS 16
1.7 THE STRUCTURE OF THE THESIS 18

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

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

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

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 *Eucalyptus urophylla* in forest households and enterprises 115

Table 4.7 Stand level rotation ages for timber only and carbon values for *Acacia mangium* in forest households and enterprises... 116

Table 4.8 Case studies used for the forest level models for *Eucalyptus urophylla* 120

Table 4.9 Forest level rotation ages with timber only and carbon values for *Eucalyptus urophylla*... 122

Table 4.10 Sensitivity analysis of the stand level carbon rotation age to carbon price for *Eucalyptus urophylla* in household and enterprise forests 124

Table 4.11 Sensitivity analysis of Faustmann rotation age to carbon price for *Acacia mangium* in forest households and enterprises 125

Table 4.12 The carbon rotation age at stand level with carbon payment scheme126

Table 4.13 Sensitivity analysis of the carbon rotation age at stand level with the planting cost subsidy for *Eucalyptus urophylla* 127

Table 4.14 Sensitivity analysis of Faustmann carbon rotation age with the planting cost subsidy for *Acacia mangium* 128

Table 4.15 Sensitivity to carbon sequestration function at stand level for *Eucalyptus urophylla* 132

Table 4.16 Sensitivity of the timber optimal rotation to λ at forest level for *Eucalyptus urophylla* 133

Table 4.17 The optimal results of all cases at an 8% discount rate and the 50 MVP for *Eucalyptus urophylla* 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 *Eucalyptus urophylla* 104

Figure 4.2 Planting costs for *Acacia mangium* 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 λ at forest level for *Eucalyptus urophylla* 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

CHAPTER ONE. INTRODUCTION

1.1 INTRODUCTION

According to the Copenhagen Accord, climate change is one of the greatest challenges of our time and a deep cut in global emissions is required to combat this problem (UNFCCC, 2009). The Copenhagen Accord also recognizes the crucial role of reducing emissions from deforestation and the need to enhance removals of greenhouse gas emissions by forests, and commits to provide funding for such actions in developing countries. Meanwhile, climate change also brings about biodiversity loss, which poses a real threat to the livelihoods, food security and health of the poor. Again, forests and changes in forest management practices can help to conserve biodiversity. Since the annual rate of natural forest loss is 0.3% (FAO, 2007) and is irreversible, planted forests appear as a "lesser evil" to protect indigenous vegetation remnants (Brockerhoff, Jactel, Parrotta, Quine, & Sayer, 2008). This study, therefore, examines changes in forest management practices to provide carbon sequestration and biodiversity conservation.

This chapter is structured as follows. The next section sets up the background for the study and presents the problem statements. The study area is described in section 1.3. Sections 1.4 and 1.5 identify research objectives and research questions, respectively. The contributions of the study are presented in section 1.6. The last section presents the structure of the thesis.

1.2 BACKGROUND AND PROBLEM STATEMENTS

1.2.1 The Kyoto Protocol and the Vietnamese Government policies

In response to climate change, country members of the United Nations Framework Convention on Climate Change (UNFCCC) proposed the Kyoto Protocol, an international agreement with legally binding measures (UNFCCC, 1997). The Kyoto Protocol sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas emissions to an average of five per cent below 1990 levels over the period 2008-2012. One of the mechanisms that countries can use to meet their targets is to plant trees (reforestation), since trees sequester carbon from the atmosphere and hence, reduce carbon dioxide concentrations. Even though it is not yet sure if the Kyoto Protocol will continue after 2012, it is almost sure that some form of international policy on climate change will continue, and the rules to be set up for reforestation programs will probably rely heavily on those developed for the Kyoto Protocol (Caparros, Cerdá, Ovando, & Campos, 2010)

The Kyoto Protocol has set up a framework for a global market of carbon credit to be formulated (via emission trading), and the optimal price of carbon is projected to rise from around $45 per metric ton in 2015 to roughly $220 in 2050 (Nordhaus, 2007). The global cost of a climate policy with forestry as an abatement option is $3.0 trillion cheaper than a policy without forestry (Tavoni, Sohngen, & Bosetti, 2007). These figures strongly suggest that carbon uptake should be introduced into the management strategy to increase the forests' values. "If society is both serious about climate mitigation and serious about containing costs, there is little choice but to develop programs that increase the stock of carbon in forests." (Sohngen, 2009, p. 5).

The Vietnamese Government ratified the Kyoto Protocol on 25 September 2002[1]. The Government has already implemented some trial projects to pay for environmental services including carbon sequestration (Ha, Noordwijk, & Thuy, 2008; Vietnamese Government, 2008). According to Phu (2008), the Government has regulated that planted forests, which are operated either by private or state organizations, are eligible for payment for environmental services after four years of planting.

This payment can be made directly to the forest owners. For example, all visitors or tourists to forests have to buy a ticket, issued by forest owners, at the entrance. After paying tax, all the money collected from the sale of tickets belongs to the forest owners. The payment can also be made indirectly from individuals or organizations who benefit from the environmental services, such as clean water, fresh air, underground water and eco-tourism; or whose activities negatively impact on forests, for example, wood processing, mineral extraction, and ceramic production.

The Government takes the responsibility for collecting this money and then pays it to the forest owners whose forests provide the environmental services. The Government also collects money from domestic and international organizations supporting environmental services and from the sale of carbon credit (Phu, 2008). For instance, the funding for the CDM project, which is jointly operated by Vietnamese and Japanese organizations, in Cao Phong district, Hoa Binh province comes from Honda Vietnam, and the sale of carbon credit, timber and other non-timber forest products (Ha, et al., 2008). In the case that the payment to forest owners is less than the costs borne by forest owners to provide the environmental services such as carbon sequestration and clear water, the Government commits to subsidize products of CDM projects (Vietnamese Government, 2007c).

[1] The Vietnamese government has not submitted a pledge to the Copenhagen Accord yet (UNFNCC, 2010)

1.2.2 The Convention on Biological Diversity

There is no doubt that biodiversity loss poses a real threat to the livelihoods, food security and health of the poor (Briefing, 2008). Yet, the rate of biodiversity loss is increasing alarmingly (Purvis & Hector, 2000), as a result of climate change, the over-exploitation of natural resources, invasive species, pollution, and institutional changes (Deke, 2007; Thomas et al., 2004). Projections of global change impacts on biodiversity show continuing and, in many cases, accelerating species extinctions, loss of natural habitat, and changes in the distribution and abundance of species and biomes over the 21st century (Leadley, Fernandez-Manjarrés, & Walpole, 2010).

The Convention on Biological Diversity (CBD) entered into force on 29 December 1993 aims at: conserving biological diversity, sustainable use of the components of biological diversity, and fair and equitable sharing of the benefits arising out of the utilization of genetic resources. The CBD states that conserving biodiversity is fundamental to achieving environment sustainability and sustainable development (CBD, 1992).

Forests provide some of the most important sources of biodiversity and are a habitat for more than half of the described territorial plant and animal species on earth (Hassan, Scholes, & Ash, 2005). The CBD addresses forests directly through the expanded programme of work on forest biological diversity (annex to decision VI/22), adopted in 2002 (CBD, 2002). This programme emphasizes conservation of forest biodiversity and requires that at least 30% of planted forests should be managed in a way that promotes biodiversity. However, the CBD has not formulated any incentive program for conserving biodiversity such as in the Kyoto Protocol.

1.2.3 Biodiversity in Vietnam

The Southeast Asia region contains the highest mean proportion of country-endemic bird (9%) and mammal species (11%) (Sodhi, Posa, et al., 2010). Being one of ten countries in this region, Vietnam is recognized as one of the most biologically diverse countries in the world (VNexpress, 2006). It has 11,458 species of fauna, 21,017 species of flora and 3,000 species of micro-organisms, and many new species which are discovered every year (An & Ha, 2006). The rich natural ecosystems of Vietnam are home to nearly 10% of the total global mammal and bird species (An & Ha, 2006).

It is estimated that there will be losses of 13–85% of all species in the Southeast Asia region by 2100 (Sodhi, Posa, et al., 2010). In Vietnam, 700 species of animals and plants are threatened with national extinction and over 300 species are threatened with global extinction (An & Ha, 2006). Deforestation is the main contributor to these biodiversity losses (An & Ha, 2006; Sodhi, Koh, et al., 2010; Sodhi, Posa, et al., 2010).

Natural forest cover in Vietnam declined from 43% of the land area in 1943 to 26% in 1993, as a result of agricultural expansion, logging, and the effects of war. Between 2000 and 2005, the natural forest cover was further reduced, however, the total forest cover in Vietnam increased to 32–37% due to reforestation (Meyfroidt & Lambin, 2008). Because of the long history of human disturbance and the continuing clearing of natural forests, however, biodiversity is still threatened in Vietnam despite the recent increase in total forest cover (Meyfroidt & Lambin, 2008).

1.2.4 Planted forests in Vietnam

There is no doubt that planted forests have multiple uses (such as carbon sequestration, soil and water protection, biodiversity conservation), however, they are still mainly managed to provide maximum income from selling timber.

Planted forests are defined as forests of predominantly introduced species established through planting and/or seeding, and forests of native species established through planting and/or seeding and managed intensively (FAO, 2007). Planted forests only account for 7% of total forest cover in the world, but provide approximately 50% of total wood production. Since wood demand continues to grow and wood supply from natural forests is decreasing, the area of planted forests is expected to further expand in future years (FAO, 2007).

In Vietnam, the area of productive planted forest[2] constitutes approximately 13.1% of the total forest area and this has increased by 11.9% per annum during the period 2002-2006 (MARD, 2007). In a time of rapid climate change, managing planted forests for multiple-use purposes is increasingly important. In addition, claims are made that Vietnam could gain a lot from engaging in the international carbon market; however, the benefits of carbon sequestration have not been adequately studied in the management of productive planted forests (Bui & Hong, 2006).

In Yen Bai province, most of the fast-growing tree species in productive planted forests are cut at the ages of 5 year (Nguyen, Nguyen, Bui, & Trinh, 2006). This cutting age is less than the optimal harvesting age that takes into account both timber production and carbon sequestration (Diaz-Balteiro & Rodriguez, 2006; van Kooten, Binkley, & Delcourt, 1995). Moreover, the majority of forest farmers apply a clear cut practice (Bui & Hong, 2006) that destroys habitat and causes serious loss of biodiversity (Pawson, Brockerhoff, Norton, & Didham, 2006). These consequences are the result of forest farmers' daily basic needs, lack of investment capital (Nguyen, et al., 2006), and no payment for environment services (Bui & Hong, 2006) among others.

Up to now, Vietnam has not had multiple-use planted forests (FAO, 2006; MARD, 2007). Nevertheless, the Vietnamese Government has recognized the

[2] This is a new definition used in State of the World Forest (FAO, 2007).

importance of multiple-use planted forests and two Decisions signed by the Prime Minister regarding productive planted forests have recently been issued. Decision No. 100/2007/QD-TTg dated July 2007 states that the Government encourages forest owners to lengthen rotation ages (Vietnamese Government, 2007b). Decision No. 147/2007/QD-TTg promulgated in September 2007 emphasizes that productive planted forests are multiple-use planted forests, and the Government subsidizes the forest owners to partly compensate them for environmental services and for low profitability of planting trees (Vietnamese Government, 2007a).

During the period 2007−2015, the area of productive planted forests will continue to expand as the result of the Five Million Hectare Afforestation Program (Vietnamese Government, 2007a) and because of a large demand for wood domestically (MARD, 2006). To increase the value of carbon sequestration and the maintenance of biodiversity while ensuring timber production, there is an urgent need to adopt an optimal management strategy for productive planted forests.

This study takes into account the benefits of timber production, carbon sequestration, and biodiversity conservation in the optimal management of planted forests. Prevailing forest management policy is managing forest at stand level, which does not allow interactions and feedback effects between forest stands within the forests. In addition, stand level management often neglects the total diversity of the entire forest which plays a potentially important role in biodiversity conservation (Armsworth, Kendall, & Davis, 2004). Economies of large scale in planting timber is also ignored in stand level management. To capture all these factors, the optimal management strategy needs to be considered at a forest level. The optimal management strategy at both stand and forest levels will be applied to household and enterprise planted forests in Yen Bai province, Vietnam.

1.3 THE STUDY AREA

1.3.1 General conditions

Yen Bai is 180 km northwest of the capital, Hanoi, with a total area of 688,292 ha, of which more than 70% is covered by mountains and highlands (Figure 1.1). The area has a tropical climate with two distinctive seasons caused by the monsoon wind. The hot wet season lasts from April to October and the cold dry season from November to March. The mean annual temperature is 22.9°C, with the highest temperature recorded 37.3°C. Annual rainfall ranges from 1,500 mm to 2,200 mm, and the average humidity is 84.06%.

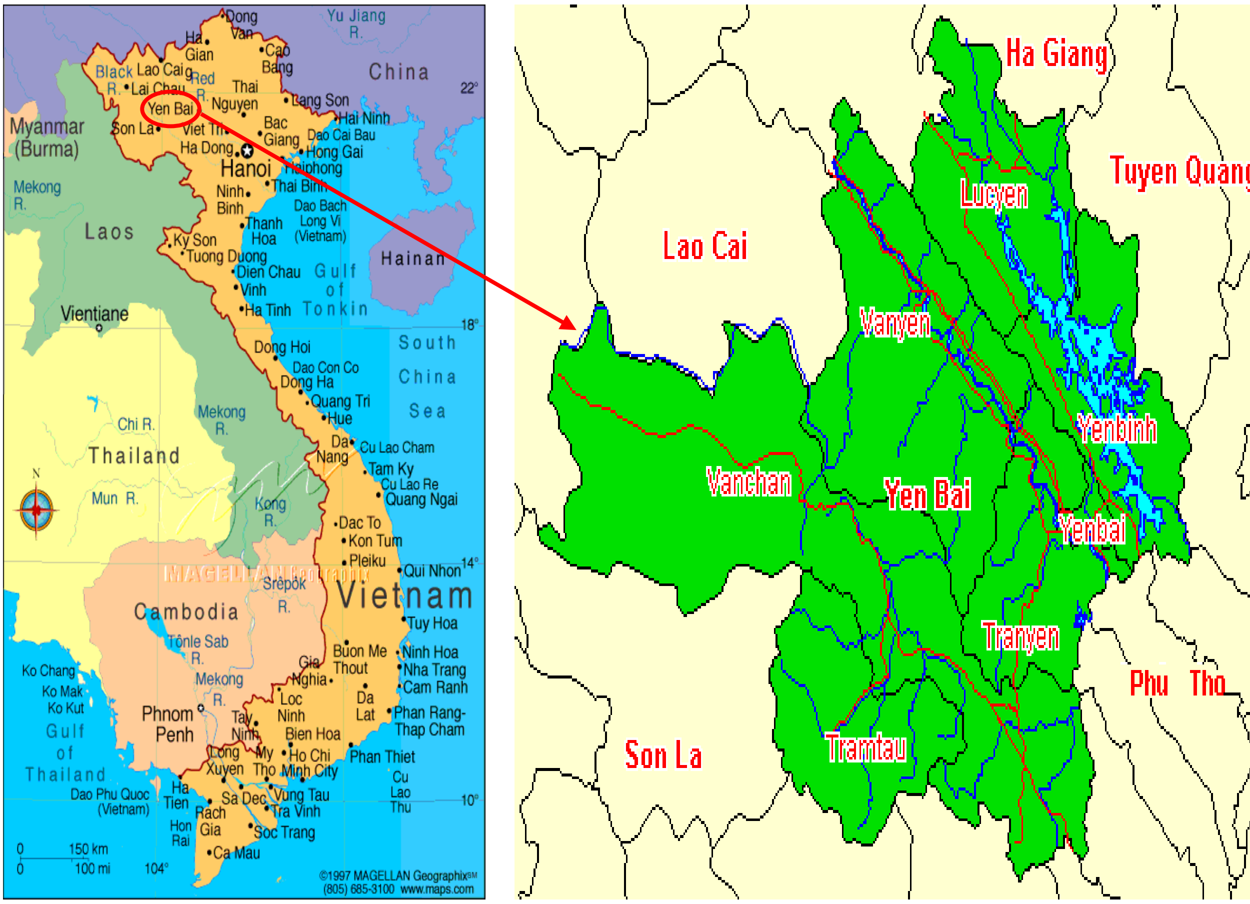


Figure 1.1 Map of Yen Bai province

Source: www.google.com.vn

1.3.2 The forest resource and legal framework

Yen Bai is a major timber supply area in Northern Vietnam. The area of productive planted forest in Yen Bai is 116,472 ha, accounting for 59.1% of the total area and 6.94% of the total productive planted forest area in Vietnam (MARD, 2007). Nine state enterprises (Yen Bai Forestry Department, 2008) and 41,000 households are involved in forest plantation (Nguyen, et al., 2006). In Yen Bai, 50% of the productive forest area is managed by Commune Committees, 42.1 % by households, 7.6% by forest enterprises, and the remaining area belongs to other institutions (Figure 1.2).

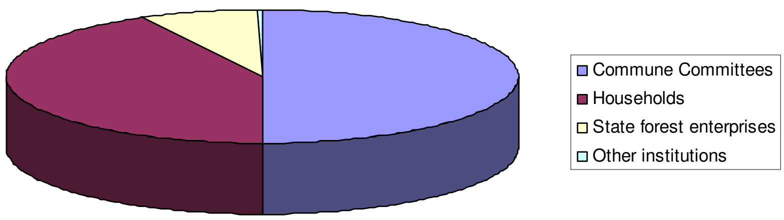


Figure 1.2 Proportion of forest land ownership in Yen Bai province

There are variations in forest investments and harvesting regimes under different types of ownership. Under the Commune Committees category, investments in planted forests are paid for by the Government, and thus, their harvesting plans must be approved by the Government. Under the households category, households are financially responsible for their investments, and they do not have to seek harvesting permissions from the Government. State forest enterprises also use Government funds for their plantation investments and must seek harvesting permissions like the Commune Committees; however, they concentrate on commercial purposes, while Commune Committees focus on the protection of natural and planted forests.

Planted forests are dominated by fast growing trees such as *Eucalyptus urophylla*, *Acacia mangium*, *Styrax tonkinensis, Manglietia conifera, Cinnamomun cassia Blume* and other native species (YenBaiForestryDepartment, 2008). *Eucalyptus urophylla* and *Acacia mangium* were both introduced to Vietnam in early 1980s, grow fast and are well adapted to local natural conditions (MARD, 2003).

In Vietnam, all forest land is under state ownership. According to Government Decree No. 163/1999/ND-CP (Vietnamese Government, 1999), forest lands are allocated and leased to individuals and organizations for long-term forestry purposes. Forest land allocated to households shall not exceed 30 ha and 50 year use right. After 50 years, the right to use the land can be extended at the request of the forest owner; otherwise it reverts back to the Government. Government Decree No. 135/2005/ND-CP (Vietnamese Government, 2005c) allows state forest enterprises to contract their land to households for a maximum of 30 years. Therefore, in principle, forest owners have sufficient land to apply sustainable management and long rotation intervals. In other words, household forest areas can be divided into pieces in order to grow multiple age class species; and households can delay harvest up to 50 years.

According to Government's Decree No. 23/2006/ND-CP (Vietnamese Government, 2006), forest owners can exchange, transfer, rent, inherit or mortgage the right to use the land they have been allocated. They can also use their land as capital for joint ventures. Therefore, forest owners could pool their land for carbon sequestration management. However, they cannot change the purpose of land use, unless approved by the Government.

Decision No. 147/2007/QD-TTg (Vietnamese Government, 2007a) states that forest farmers who are allocated forest land are given a subsidy of 1.5 million VND per ha per rotation and can keep 100% of the forest products. However, they have to pay a duty of 80 kg rice per ha per rotation (approximately 0.24 million VND per ha per rotation). Forest owners are required to replant the forests within 12 months after harvest. According to Government Decrees No. 106/2004/ND-CP (Vietnamese Government, 2004) and No. 20/2005/ND-CP (Vietnamese Government, 2005d), forestry projects can borrow up to 85% of the total project's capital and for up to 15 years. A more recent policy, Decision No. 443/2009/QD-TTg (Vietnamese Government, 2009) states that the Government subsidizes interest rate from bank loans up to 4%/ year and for 2 years.

Both household farmers and state forest enterprises are allocated forest land for 50 years. However, there are some different features between households and state enterprises in terms of legal requirements and forest management practices. First, forest land which is allocated to households shall not exceed 30 ha, while state enterprises can be allocated up to a thousand ha. Households determine how much money to invest into their forests. But planting costs of state enterprises, which include seedlings, labour, fertilizers, tending cost up to year 3, and other costs, are regulated by the Government. For example, state enterprises are not allowed to spend more than 10% of the total planting costs for management costs (MARD, 2005). State enterprises have to spend more money on forest protection (against thieves) than households do. There are only a small number of household farmers who borrow from the bank to invest into their forests. They normally use their own money or borrow money from relatives and friends.

1.3.3 Market conditions

As stated in Government Decree No. 23/2006/ND-CP (Vietnamese Government, 2006), forest owners are free to sell their forest products. Prime Minister Decision 661/1998/QD-TTg (Vietnamese Government, 1998) encourages forest owners to plant tree species that have high economic values. Decision No. 40/2005/QD-

BNN (Vietnamese Government, 2005a) allows forest owners to make their own decisions about harvest ages of timber and clear-cut sizes. Decision No. 100/2007/QD-TTg (Vietnamese Government, 2007b) states that the Government encourages forest owners to lengthen rotation ages. However, there is no specific policy that persuades forest owners to maintain longer rotation.

According to Nguyen, et al. (2006), there are two types of timber dominant in Yen Bai: small-size timber used for making wood-chip, pulp and construction work; and large-size timber, around 13-15 years, for making exported products. Small-size timber end-users include local small-scale wood-processing units, wood-chip factories, Bai Bang paper mill, and Cau Duong match factory. Large-size timber end-users are wood-processing factories, local carpenters, and constructing companies. Timber can be sold directly by forest owners to timber end-users or through timber collectors and/or timber wholesalers and/or licensed trade individuals and organizations.

According to some forest owners[3], they have no difficulties in selling their timber and timber price varies with tree ages or diameters. Forest management costs include planting cost, tending cost, protection cost, land tax and bank interest. There are three main types of timber price: stumpage price, price at landing 1, and price at buyer's place[4]. Transportation costs make up a large proportion of the timber price. Growers also recognize that selling large-size timber is more profitable than small size-timber. However, they do not harvest tree later because of bank loans and illegal logging for forest enterprises, and of daily basic needs and lack of capital for households.

[3] Personal communications

[4] Landing 1 is a place nearby forests that forest owners in this region unload their raw timber for business men to buy and transport to wood-processing companies or other users. Buyer place implies location of wood-processing companies or of other users. It means that raw timber is transported to door.

The study of Nguyen (2009) shows that export revenue of processed-wood products has increased dramatically over the last several years. However, 80% of the raw wood to produce these processed-wood products is imported. The import price of *Eucalyptus* is 2.9 million VND/m^3 and *Acacia* is 1.5 million VND/m^3; these are much higher than domestic timber prices for the same tree species. Moreover, transportation cost accounts for 27% of total import price. Eighty percent of wood-processing factories are located in the southern part of Vietnam.

1.4 RESEARCH OBJECTIVES

1.4.1 General objectives

This research studies the optimal management strategies for planted forests from a private and societal perspective, and designs an optimal public policy for promoting biodiversity in planted forests. While private forest owners take into account the value of timber production and carbon sequestration, social managers consider not only these same values but also biodiversity maintenance in harvesting decisions.

1.4.2 Specific objectives

The specific research objectives are as follows:

1. To determine the planting and harvesting strategies of a forest which maximize net returns from selling timber and sequestering carbon.

2. To determine the planting and harvesting strategies of a forest which maximize net returns from selling timber, sequestering carbon, and maintaining biodivesity.

3. To compare the optimal harvesting strategies with the actual management strategies in Yen Bai province, Vietnam for *Eucalyptus urophylla* and *Acacia mangium*.

4. To analyse the sensitivity of the optimal management strategy to timber price, carbon price, discount rate, carbon payment scheme, planting cost subsidy, carbon sequestration function, and the level of economies of planting scales, *ceteris paribus*.

5. To recommend policy implications to further develop multiple-use forests (timber production, carbon sequestration, and biodiversity conservation) in Vietnam.

1.5 RESEARCH QUESTIONS

1.5.1 Optimal forest management for timber production and carbon sequestration

From a private perspective (i.e. maximizing profit without considering biodiversity benefits), the research attempts to answer the following questions at both stand level and forest level models:

1. What rotation ages are currently applied for *Eucalyptus urophylla* and *Acacia mangium* in Yen Bai province, Vietnam?

2. How much does tree planting cost? What are timber prices for these two tree species?

3. Would forest owners be willing to delay their harvest if they were financially supported? If yes, for how long? How much money would they expect to be paid in order to delay?

4. Which pattern of planting and harvesting trees should a forest owner follow in order to maximize the net present value from timber harvesting and carbon sequestration?

5. What are the differences in the net present value (NPV) and the rotation age (T) between two optimal management strategies that consider or do not consider the value of carbon sequestration?

6. What is the difference in rotation age between the optimal and the actual management strategies?

7. How does the optimal management strategy vary with a change in timber price, carbon price, discount rate, carbon payment scheme, planting cost subsidy, carbon sequestration function, and the level of economies of planting scales, *ceteris paribus*?

1.5.2 Optimal forest management for biodiversity conservation

From a societal perspective, with given initial stages of planted forests, the research attempts to answer the following questions:

1. Which pattern of planting and harvesting trees should a forest owner follow in order to maximize the net present value from timber harvesting and carbon sequestration, and accommodate a minimum viable population of birds?

2. What are the differences in the NPV and T between two optimal management strategies that consider or do not consider a minimum viable population of birds?

3. How does the optimal management strategy vary with a change in the MVP, the discount rate, timber price, and carbon price, *ceteris paribus*?

1.5.3 Policy tools and the optimal level of direct payments

The research attempts to address the following questions in order to recommend a suitable policy tool for promoting biodiversity in planted forests.

1. What are the attitudes of forest owners towards biodiversity conservation in planted forests?

2. What policy instruments are relevant to fill the gaps in the NPV and T between the current forest management strategy and the optimal strategy when biodiversity conservation is considered?

3. What is the optimal level of direct payments to encourage forest owners to enhance biodiversity in planted forests?

1.6 CONTRIBUTIONS

The study contributes to the literature by finding and analysing the optimal management strategy at a forest level for planted forests when carbon sequestration and biodiversity conservation are considered. The optimal forest management model of Faustmann (Faustmann, 1849) is extended to include both biodiversity maintenance and carbon sequestration. The model is also extended to incorporate multiple forest stands, spatial arrangements of forest stands, and spatial interactions among forest stands. In this context, spatial arrangements refer to how stands are put together geographically, and spatial interactions are defined as the economies of planting scale.

In Vietnam, all forest land is under state ownership and forest land allocated to households shall not exceed 30 ha and 50 year-land-use right (Vietnamese Government, 1999). These features of household ownerships make this type of forest ownership in Vietnam different from other types of ownerships in other nations, such as individual private owners, non-industrial forest owners and private enterprises, and all of which have been studied in the literature (Englin & Callaway, 1993; Tahvonen, 1999; van Kooten, et al., 1995).

Most of the studies on optimal forest management are for slow-growing trees based in temperate forests and in developed countries. It is important to recognize that forest management for even the same dominant trees species may still be different in different countries (Diaz-Balteiro & Rodriguez, 2006). This research contributes to the body of the literature by analyzing the management of tropical planted forests in a developing country, where the removals of emissions from forests and biodiversity conservation need to be enhanced (CBD, 2002; UNFCCC, 2009).

The study contributes to the literature by providing policy conclusions for internalizing carbon sequestration and policy tools for enhancing biodiversity in planted forests under a particular socio-economic context of Vietnam. These public policy tools will be a useful frame work for policy makers to develop multiple-use plantation forests. Such policy tools are important since, currently, there is no multiple-use plantation forest in Vietnam (FAO, 2006) and the government is very keen to develop it. The study also provides the optimal level of direct payments to induce a forest owner to adopt the optimal management strategy from a societal perspective.

The optimal forest management strategy will help forest owners make their plans and manage their forests profitably when carbon sequestration has market value. The results will be used to recommend policy to the Ministry of Agriculture and Rural Development to achieve a desired management strategy for different tree species and ownerships; to cope with a change in market conditions; to encourage carbon storage; and to enhance biodiversity in Vietnam.

1.7 THE STRUCTURE OF THE THESIS

The thesis is organized as follows: Chapter 2, the literature review covers the optimal forest management models with timber production, carbon sequestration, biodiversity conservation, and uncertainties. The literature on forest public policies is also discussed in this chapter. Chapter 3 explains the methodology of the study, including the background for the biodiversity model, the optimization models, and the survey of forest owners in Vietnam. Results and discussion of the survey, the optimization models, and policy tools are presented in Chapter 4. Finally, Chapter 5 summarizes and concludes the thesis.

CHAPTER TWO. LITERATURE REVIEW

2.1 INTRODUCTION

Optimal forest management has been investigated for around hundred and fifty years. Over time the focus of the optimization problem has been extended from the maximization of the private and economic benefits of single stand forests to multiple stand forests and from a single rotation to an infinite sequence of rotations. Additional extensions have included the move from deterministic to stochastic models and the incorporation of other than timber values.

As climate change and biodiversity loss are today among the greatest challenges facing the 21st century, carbon sequestration and biodiversity preservation, two of the important ecosystem services of forests, have been incorporated in the decision making process for optimal forestry management from society's point of view.

In this chapter, the literature on optimal forest management will be reviewed with special emphasis on the role of forests in carbon sequestration and the relationship between biodiversity and planted forests. Gaps in the literature will be identified especially where models fail to provide the necessary information for decision makers to determine optimal management strategies.

The structure of this chapter is as follows. The next section reviews literature on optimal forest management. Section 2.3 presents the importance of biodiversity, its measurement and valuation problems and how forest management affects it. The next section will review policy tools that can be used in case private decisions need to be aligned with socially optimal decisions. The final section presents a synthesis of the chapter and identifies some of the gaps in the literature.

2.2 OPTIMAL FOREST MANAGEMENT

One question of importance to forest owners is the optimal time at which to fell trees. The answer is obtained by choosing the age of timber at which the net present value of benefits from the stand of timber is maximized. This process to determine the optimal harvest age is known as optimal forest management. The benefits from the stand of timber can be only the monetary value from selling timber, or can include the benefits from carbon sequestration, amenities, and biodiversity conservation.

The following sections discuss the literature regarding optimal forest management which mentions these benefits in turn. Since the provision of biodiversity conservation may not have an economic value, discussion regarding a subsidy for promoting biodiversity is also provided in case the optimal harvest decision from the forest owners' views fails to include biodiversity conservation benefits.

2.2.1 Optimal forest management when only timber has market value

This section classifies the literature on optimal forest management into two main categories: stand and forest level models. A forest usually consists of many stands, which are contiguous groups of trees sufficiently uniform in species composition, arrangement of age classes, site quality, and condition to be distinguishable units (Smith, Larson, Kelty, & Ashton, 1997). Thus, a forest level model is more complicated compared to a stand level model, and hence, the literature regarding forest level management is poorer than stand level management.

The optimal management strategy for a single stand forest was developed by Faustmann (1849). He calculated the value, which bare forest land possesses when in forestry use, of an even-aged stand under a clear-cut management practice. A stand was defined as a "working section", which is under the same silvicultural system and rotation and can be considered as a uniform whole for yield calculation. He assumed that the land has no other uses, in other words, only the value which bare forest land possesses when in forestry use is calculated. Let *V* be the value of bare forest land in forestry use, the Faustmann formula is as follows.

$$V = \frac{(p-c)v(T)e^{-rT} - k}{1 - e^{-rT}}$$

Where: *T* is stand age at which the forest is clear-cut, *k* replanting cost at the start of every rotation, *p* price of timber, *c* harvesting cost, *v(T)* timber growth function, and *r* interest rate. To solve the problem, setting the derivative of *V* equal to zero yields:

$$pv'(T) - rpv(T) - rV = 0$$

This equation implies that it is optimal to clear-cut a stand when the growth rate of the value of the standing trees equals the interest on the standing trees and bare land. The optimal rotation period is increasing with a rise in *k* and decreasing with a rise in *p* and *r.* The Faustmann model has provided the usual starting point for understanding the economics of forestry. It has also been used in forestry operations and has served as a highly useful and influential framework for various extensions in forest economics (Tahvonen, 2004a). The Faustmann model, however, is far from reality: it describes the problem for a single age class only, and assumes no uncertainty and no environmental preferences.

The more general problem of harvesting a forest area with many stands (i.e. different age classes) was well known even before Faustmann. The problem, which has a long history in forest science, is to find an age class-specific timber harvesting programme over time that maximizes the economic surplus from forestry (Davis & Johnson, 2001; Leuschner, 1990).

In the forest economics literature, the optimal management strategy for a multiple stand forest was first introduced by Mitra and Wan (1985; 1986). Their studies represent remarkable progress in understanding the forestry age class problem (Tahvonen, 2004a). They applied a dynamic programming approach and found that: (i) if the utility function is linear, the Faustmann periodic solution is optimal; and (ii) if the utility function is increasing and strictly concave, an optimal solution converges to the maximum sustained yield[5] solution.

2.2.2 Optimal forest management including amenity values and carbon sequestration

The incorporation of amenity values and carbon sequestration into a forest optimization model is discussed in this section. Again, the section is divided into stand level and forest level categories. Solutions to these models are compared to the Faustmann model solution.

Hartman (1976) extended the Faustmann model to include the amenity value of forests. He considered a forest growing on a given plot of land, to which a clear-cut practice was applied. Timber prices were assumed to remain constant over time and forest output was considered to be small relative to aggregate supply. Let *V(T)* be the timber growth curve, giving the stumpage value of the timber in a forest at the age *T*. The slope of *V(T)* is initially positive and increasing, then increasing at a decreasing rate, and finally levelling off as the forest reaches a mature steady state. Let *F(T)* denote the value of the recreational and other

[5] Maximum sustainable yield stands for maximizing the mean annual increment (Hyytiainen & Tahvonen, 2003)

services flowing from a standing forest of age *T*. The slope of *F(T)* is initially positive and then increasing at a decreasing rate to a maximum. The recreational and timber stumpage values are dependent on the age of the forest. Planting costs and other outlays are ignored. The optimal age of harvest is the same for each regeneration of timber and is denoted by *T*. Let *t* be a point of time. The objective is to maximize the present value from selling timber and the provision of recreational and other services:

$$PV = \frac{e^{-rT}V(T) + \int_0^T e^{-rt}F(t)dt}{1-e^{-rT}}$$

Setting the first derivative of *PV* to zero yields:

$$\frac{V'(T)}{V(T)} = r\{\frac{1}{1-e^{-rT}} + \frac{\int_0^T e^{-rt}F(t)dt}{V(T)(1-e^{-rT})}\} - \frac{F(T)}{V(T)}$$

Hartman found that the optimal rotation is longer or shorter than the Faustmann rotation if environmental values increase or decrease with stand age. He concluded that "the presence of recreational or other services provided by a standing forest may well have a very important impact on when or whether a forest should be harvested. Those models, which consider only the timber value of a forest, are likely to provide incorrect information in the many cases where a standing forest provides a significant flow of valuable services" (Hartman, 1976, p. 57). The shortcomings of his model are that it did not include planting costs and only considered a one-stand forest.

Van Kooten, Binkley and Delcourt (1995) studied the effect of carbon taxes and subsidies on the optimal forest rotation age and concluded that the carbon optimal rotation age is a bit longer than the Faustmann rotation. In their model, carbon benefits are a function of the change in biomass and the amount of carbon per cubic meter of biomass. Carbon sequestration at any time is given by $\alpha v'(t)$, where α is (metric) tons of carbon per m^3 of timber biomass. The amount of carbon released into the atmosphere depends on the fraction (β) of timber that is harvested and goes into long-term storage in structures and landfills. Payment for carbon is made yearly and the forest owner has to pay a tax for cutting the trees. The price of carbon is constant over rotation length. Let *PV* be the net present value from selling timber and sequestering carbon:

$$PV = \frac{P_c\alpha\left[v(T)e^{-rT} + r\int_0^T v(t)e^{-rt}dt\right]}{1-e^{-rT}} + \frac{\left[P_F - P_c\alpha(1-\beta)\right]v(T)e^{-rT}}{1-e^{-rT}}$$

Where: P_c is the price or implicit social value of carbon that is removed from the atmosphere, α is (metric) tons of carbon per m^3 of timber biomass, $v(t)$ refers to the amount of timber growing on a stand at time t, T is the rotation length (with the objective being to find the optimal value of T that maximizes the NPV), r is the discount rate, P_F refers to the net price of timber per cubic meter, and β represents the fraction of timber going into long-term storage. The optimal rotation age that takes into account both commercial timber values and carbon uptake values is found by differentiating the above equation with respect to T and setting the result equal to zero.

$$(P_F + P_C\alpha\beta)\frac{v'(T)}{v(T)} + rP_C\alpha = \frac{r}{1-e^{-rT}}\left[(P_F + P_C\alpha\beta) + \frac{rP_C\alpha}{v(T)}\int_0^T v(t)e^{-rt}dt\right]$$

$P_c = 0$ gives the Faustmann results, and $P_F = 0$ and $\beta=0$ gives the Hartman rotation.

Van Kooten et al. (1995) concluded that carbon subsidies and taxes may achieve desired carbon sequestration in forests in developed countries. The inclusion of the external benefits from carbon uptake results in rotation ages only a bit longer than the Faustmann rotation age. Under some tax regimes, it may be socially optimal never to harvest the trees. In van Kooten et al.'s study, the rate of tree growth is an important determinant of carbon benefits, while in Hartman's model, the age of trees is important for the value of recreation. The van Kooten et al.'s model did not include other external benefits (e.g. those related to the amount of standing timber) beyond the carbon uptake benefits (e.g. those related to the annual change in timber volume).

Also considering carbon sequestration, Diaz-Balteiro and Rodriguez (2006) employed a dynamic programming approach and showed that the optimal rotation age is sensitive to changes in the discount rate and the carbon price. Again, Gutrich and Howarth (2007) confirmed that when carbon storage brings benefits to society, the optimal rotation ages are extended depending on the forest types. They also pointed out that in the absence of policies to promote forest carbon storage; forest owners employ clear-cut harvesting regimes with a relatively short rotation age. Other studies on single stand forest shows that carbon rotation age differs from timber rotation age including Englin and Callaway (1993), Guthrie and Kumareswaran (2009), Thompson, Adams, and Sessions (2009), and Köthke and Dieter (2010).

With regard to forest level models, Gutierrez, Zapata, Sierra, Laguado and Santacruz (2006) used a genetic algorithm to find optimal management regimes for multiple stand forests under the Clean Development Mechanism[6]. They discovered that the optimal rotation age is increasing with an increase in carbon price and the profitability of the forest is very sensitive to its size, especially when

[6] The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialised countries with a greenhouse gas reduction commitment (called Annex B countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. (UNFCCC)

forest size is less than 2,000 ha. They also concluded that information on carbon sequestration in the tropics is scare. In their study, however, all forest stands are at the initial age of zero and the study is based on the assumption of no spatial interdependence among forest stands.

2.2.3 Optimal forest management with biodiversity maintenance

While for plantation forests the value of timber and sequestered carbon can be obtained from the literature and market information, the value of biodiversity is not always available. One reason is that biodiversity benefits are not readily marketable. The other is the common belief that plantation forests provide little in terms of biodiversity benefits, especially plantations in tropical countries. Consequently, the literature on valuing the biodiversity benefits of plantation forests is limited.

Efforts have been made to put a dollar value on biodiversity in planted forests. For example, Pouta (2005) used a contingent valuation method to analyze people's beliefs on biodiversity conservation. Her results show that the value of biodiversity is 40 EUR/ha. Employing a choice modelling approach, Rivas Palma (2008) found that the environmental benefits in planted forests in New Zealand range from 100 to 900 NZD/ha. However, Lindhjem (2007) claimed that willingness to pay is insensitive to the size of the forest and tends to be higher if people are asked as individuals rather than on behalf of their household.

The value of biodiversity in planted forests has been used to analyse the optimal forest management at a stand level. Koskela, Ollikainen and Pukkala (2007a) incorporated the value of biodiversity of 40 EUR/ha by Pouta (2005) into Hartman's model (1976). They found that the optimal rotation age with biodiversity is longer than the Faustmann one. This result is in line with the findings by Juutinen (2008) who also internalized the value of biodiversity into optimal forest management. Again, the weakness of these models is that they consider only a single stand forest, which is far from the reality.

Optimal forest management has been extended to include environmental benefits other than carbon sequestration and biodiversity preservation, such as water benefits (Chisholm, 2010; Creedy & Wurzbacher, 2001); uneven-aged stands (Tahvonen, Pukkala, Laiho, Lähde, & Niinimäki, 2010); and thinning (Hyytiainen & Tahvonen, 2002). Considering these benefits and features of forests in a forest level model would be interesting, however, it is too complicated to solve the model.

With regard to forest level models, the forest science literature has incorporated biodiversity-related constraints, such as species persistence, or old-growth benefits, into harvesting problems. Studies that included species persistence are Calkin et al. (2002), Doherty, Marschall, & Grubb (1999), Nicholson et al. (2006), and Polasky, Nelson, Lonsdorf, Fackler, and Starfield (2005); and old-growth benefits are Caro, Constantino, Martins, and Weintraub (2003), Khajuria, Laaksonen-Craig, and Kant (2008), Latta and Montgomery (2007), and Montgomery, Latta, and Adams (2006). However, these studies do not address optimal rotation ages.

In the forest economics literature, Tahvonen (2004b) included old-growth values into his multiple stand model as follows.

$$MaxV = \sum_{t=0}^{\infty} \left[U(c_t) + A(h_t)\right](1+r)^{-t}$$

Where U denotes a utility function for timber output and c_t the volume of timber, A is the utility function related to environmental characteristics, and h_t a function of old growth conservation. The results of Tahvonen's analysis show the existence of an optimal long-run stationary continuum for land allocation between timber production and old-growth conservation. At each point of the continuum, timber is produced under the Faustmann rotation[7]. The study of Tahvonen was, however, based on the assumption of no spatial interaction among forest stands.

Spatial interactions can be interpreted as either biological or financial interactions. To capture biologically spatial interactions, Swallow, Talukdar and Wear (1997) employed a dynamic programming approach and allowed optimization of timber harvesting decisions in a forest consisting of two stands. In their study, spatial interactions among forest stands refer to the dependence of the non-timber benefit function for any stand on its own age and the ages (or conditions) of the neighbouring stands. Their results show that the nature of stand interactions may alter the optimal management plan substantially. These results are in line with the findings by Amacher, Koskela, and Ollikainen (2004) who employed a similar definition of spatial interactions and of optimization method. Koskela and Ollikainen (2001) considered a forest including one focal stand and an exogenous adjacent stand which affects the amenity production of the focal stand. They showed that the rotation age may increase with timber price rather than decrease as in the Faustmann model. However, their models included only two stands, while in reality, the number of stands in forests is much higher.

Touza, Perrings, and Chas Amil (2009) extended a single stand forest model by Touza, Termansen, & Perrings (2008) to analyse a multiple-stand forest (with more than two forest stands). They considered non-timber benefits as a function of total tree biomass of all the stands. Their results show that spatial interactions among forest stands do change the optimal rotation age at the forest level compared to the stand level. Similar to other earlier studies at a forest level, their model did not specify spatial arrangements among forest stands.

[7] This means that the optimal management strategy divides forest land into two regions, one is for timber production and follows Faustmann rotation, and the other is for old growth conservation and applies an extended rotation.

Financially spatial interactions refer to economies of harvesting or planting scale. At stand level, Termansen (2007) included economies of harvesting scale in his analysis and found that the harvesting costs have a significance impact on the optimal harvest strategy. His results also suggest that the optimal rotation does not always decrease with interest rate as in the Faustmann model. At forest level, Rose and Chapman (2003) analysed the role of economies of scale in harvesting of timber and non-timber management strategies. Their results showed that the manager's decisions can be misleading if spatial interactions are ignored. Again, their study included only two one-hectare stands.

2.2.4 Optimal forest management under uncertainty

Recently, forest optimization models have accounted for uncertainty associated with forestry investments by allowing stochastic variations in, e.g. timber prices, carbon prices, timber growth and discount rates. A stochastic process can be understood as a collection of random variables, which are indexed by a time parameter (Haigh, 2005). When the distribution of these random variables satisfies certain properties, a stochastic process is referred to as a geometric Brownian motion, a diffusion process, or a mean-reverting process. For example, a geometric Brownian motion is a continuous-time stochastic process in which the logarithm of the randomly varying quantity follows a Brownian motion (Ross, 2007). A mean-reverting process is a process in which the random variables tend to revert to a "normal level" with a certain speed of reversion, such as the price of oil tends to drawback towards the marginal cost of oil production (Dixit & Pindyck, 1994). These different approaches to model uncertainty have been applied to forest optimization models both at the stand and forest level.

Uncertainty has been incorporated in a single and an ongoing rotation (Faustmann formula). Depending on assumptions made, some authors found that the optimal rotation age is independent of timber price uncertainty, while others show that the optimal rotation length and the net present value are positively correlated to price uncertainty. Using continuous time, Clarke and Reed (1989) assumed timber price to follow a geometric Brownian motion and timber growth evolving as a diffusion process. For a single rotation, their results show that price and growth uncertainties lengthen rotation age and increase NPV value. For the Faustmann rotation, they were unable to solve their model when both stochastic price and stochastic growth were considered. When only price uncertainty was incorporated, they show that price uncertainty has a small effect on rotation age, but substantially increases the NPV.

Employing a similar methodology, though using a different specification for the timber growth process, Reed and Clarke (1990) obtained results consistent to those of Clarke and Reed (1989); except that in the single rotation, they found that price uncertainty has no effect on optimal policy. Thomson (1992) extended the Faustmann model to include timber price uncertainty. He used a binomial pricing model and specified timber price as a lognormal stochastic process. Using dynamic programming technique for both the Faustmann and his models, the author showed that price uncertainty induces forest owners to lengthen their optimal rotation age compared to the Faustmann solution. Moreover, his results suggested that NPV is positively correlated with timber price fluctuations.

Beside stochastic price and stochastic growth, other types of uncertainty have also been taking into account. Alvarez and Koskela (2006) assumed interest rate evolving as a parameterized mean-reverting process and found that interest rate uncertainty increases rotation age under risk aversion. Motoh (2004) studied the optimal rate of use of a natural resource under uncertainty with catastrophic risk. They adopted the stock of a natural resource (in quantity) following a geometric Brownian motion before catastrophic risk occurs, and the catastrophic risk is described as a Poisson process. They used stochastic dynamic programming to maximize expected discounted utility over an infinite horizon. They reported that the optimal rate of use of the natural resource increases with uncertainty or catastrophic risk.

More recently, a real option approach has been used to deal with uncertainty in forestry economics. Insley (2002) solved a continuing rotation using the Hamilton-Jacobi-Bellman technique under a mean-reverting or geometric Brownian motion price process with deterministic volume. She argued that specifying timber price as a mean-reverting process is more rational than a geometric Brownian motion. Under a mean-reverting price, uncertainty impacts significantly on the optimal rotation period and the option value. Chladna (2007) applied a real option approach to analyse optimal single rotation for single stand forest under timber price and carbon price uncertainty. The author specified timber price as a mean-reverting process and carbon price as a geometric Brownian motion process. Employing dynamic programming technique, this paper showed that stochastic timber price and/or stochastic carbon price extend the optimal rotation length. This effect, however, is small when carbon price is low.

At the forest level, Tahvonen and Kallio (2006) extended Reed and Clarke (1989; 1990) to include risk aversion, age class structure, and planting cost. They specified timber price as a geometric Brownian motion or a mean reverting price process. Due to complexity of the problem, the authors used discrete time for their model and applied a stochastic programming technique to solve the model. In contrast to the literature, which mostly discusses single stand forests, the paper showed that price uncertainty may shorten optimal rotation age. This result follows from their assumption that only replanting cost has a significant role in determining cost factor, in contrast to earlier work that only harvesting cost is costly. The authors adopted a short planning horizon, $T=13$. This paper ignored environmental values of forests.

In summary, the literature about uncertainty at both the stand and forest levels shows that uncertainty does affect the optimal rotation age of single and multiple-stand forests. The impact on the rotation age differs according to assumptions made about the type of uncertainty and the forest owners' attitude to risk.

2.2.5 Optimal forest subsidy for promoting biodiversity

The literature mentioned in section 2.2.3 shows that the optimal rotation age under the presence of biodiversity value differs from the Faustmann rotation age. Hence, there is a gap for the government to encourage forest owners to follow the biodiversity rotation age via policy tools. Research at a stand level has been conducted to determine the best policy tools for the government to solve this problem.

Optimal biodiversity rotation ages, at a stand level, for planted forests when retention trees (i.e. trees left standing after harvest) are the key instrument in promoting habitat and species diversity have been developed by Koskela, Ollikainen and Pukkala (2007b). They assumed that the government punishes landowners for a private rotation age which is too short, and bribes landowners to leave retention trees. They solved first the socially optimal rotation age and the volume of retention trees, and compared this solution with the private solution with landowners behaving according to either Faustman or Hartman models. They used a willingness to pay of 40 EUR/ha/year as a value for biodiversity. Their results show that a combination of retention tree subsidy and tax instrument are needed to induce the landowner to lengthen the private optimal rotation period and to provide an incentive to leave retention trees. However, their biodiversity index, which includes volumes of different tree species, volumes of 10-cm diameter classes, and volumes of deadwood components (standing deadwood and down-wood of different tree species), is too complicated for use in real-world applications.

To the best of my knowledge, there is currently no study at a forest level that investigates and discusses, in terms of optimal forest management, how government incentives might affect a private manager's decisions concerning harvesting and investment. There are several studies that analysed the impact of public policies on private harvest volumes, but did not show how government incentives affect the optimal rotation age. For example, a framework for public policy analysis was developed by Adams, Alig, McCarl, Callaway and Winnett (1996) by analysing the impact of public harvest policies on private harvest volumes and wood types. Adams and Latta (2005) showed that the level of government subsidy provided for thinning in national forests does have impacts on the harvest volumes from the private forests. Murray and Abt (2001) compared the net present values of alternative management regimes to derive the compensation price premium for eco-certified forestry.

2.3 ENHANCING BIODIVERSITY IN PLANTED FORESTS

2.3.1 Definition of biodiversity and its importance

Forests are home to more than half of the known terrestrial plant and animal species (Hassan, et al., 2005). Moreover, as the loss of natural forests is irreversible, planted forests appear as a "lesser evil" to protect biodiversity (Brockerhoff, et al., 2008). Thus, enhancing biodiversity in planted forest is an urgent and important issue. The following paragraphs present the definition of biodiversity and its importance in economic terms.

Biodiversity is also termed biological diversity. It has been defined as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part” (CBD, 1992). This means that biodiversity has three levels of meaning. It applies at the genetic level with genetic diversity. It applies at a species level with species diversity. Finally, it applies in ecological levels with ecosystem diversity. Genetic diversity refers to the variety of the genes possessed by the individual micro-organism, plant, and animal. Species diversity can be described as the richness in the number of species in a given area. Ecosystem diversity refers to the variety of habitats, biotic communities and ecological processes in the biosphere and within ecosystems (Pearce & Moran, 1994). These different levels of biodiversity compound the difficulty of measuring the biodiversity of an area, which is discussed in section 2.3.2.

Biodiversity is important to human communities for a number of reasons, such as positive production effects, a buffer against disease or pests, and provisions of a number of ecosystem benefits and direct values to people. Biodiversity also provides a source of traditional medicines and pharmaceutical discoveries, foods, fuel, furniture, construction materials, employment and income.

An important function of biodiversity is its impact on production. A high level of biodiversity tends to increase the productivity of natural resources embedded in terrestrial or aquatic ecosystems. On average, plant systems with more biodiversity are more productive than those with less (Tilman et al., 1997). Empirical results show that a rise in species evenness, that is abundance of a species, can induce a high level of biomass production (Wilsey & Potvin, 2000). A good example is that mixed forests have higher wood productivity than monoculture forests and wood production is positively correlated with species richness (Vila et al., 2007). Regarding aquatic ecosystems, marine biodiversity loss leads to a reduction in the ocean's capacity to provide food (Worm et al., 2006).

A high level of biodiversity, however, could lead to a reduction of production in some cases. For instance, the agricultural industry in New Zealand relies heavily on honey-bees as pollinators to increase productivity. The invasion of the varroa mite (*Varroa destructor*), an external parasite of honey bees, in New Zealand, however, has reduced honey-bee populations. This not only affects the bee keeping industry, but also damages crop pollination, thus decreasing agricultural production (Biosecurity New Zealand, 2009; Stevenson, Benard, Bolger, & Morris, 2005).

Biodiversity can be considered as an insurance asset to reduce risks from the spread of pests and diseases that can have adverse impacts on food production or human health. When people increase the area of a crop that is commonly grown, they also raise the possibility that this crop will be attacked by a new pest

(Weitzman, 2000). Since the ecosystem is highly interdependent, the extinction of a species can cause a serious and long-term consequence to humanity. For example, the extinction of the passenger pigeon brought about the outbreak of Lyme disease a century later (Blockstein, 1998). In this situation, without reserves of genetic variability we may not be able to develop varieties of plants and animals that can resist the evolving pests (Heal, 2004).

Biodiversity plays a crucial role in supporting the proper functioning of ecosystems. Biodiversity loss can reduce both the ocean's ability to recover after perturbation and its ability to ensure water quality (Worm, et al., 2006). Moreover, biodiversity is vital in maintaining the resilience of the ecosystem to environmental shocks (Tilman & Downing, 1996). Resilience refers to the resistance of an ecosystem to perturbation and to the speed of recovery. When environmental shocks occur, an ecosystem that lacks the resilience property could result in extinction (Holling, 1973). Further, loss of a keystone species may also reduce the capacity of the ecosystems to adjust to ever-increasing rates of environmental change (Chapin et al., 1997). Species with similar ecological effects can differ in their environmental responses, such as influencing water and nutrient dynamics and tropic interactions. Thus, loss of these species affects the adjustment ability of an ecosystem to environmental change.

Biodiversity is also vital to many communities around the world as a source of traditional medicine, food, fuel, furniture, construction materials, employment and income. Wildlife can contain pharmaceutically useful compounds, such as occurred with the rosy periwinkle or Pacific yew. In addition, many communities in rural areas in the developing world, still depend on wild herbs and plants for medicine. For at least 75% of the world's population, traditional medicine is the only source of health care available for the prevention and treatment of diseases (Alves & Rosa, 2007; Rijsoort & Pater, 2000). It is estimated that 50,000 – 70,000 plant species are used in traditional and modern medicine throughout the world (TRAFFIC, 2009). In South Africa, a significant number of plant species are used for medical treatment (Light, Sparg, Stafford, & van Staden, 2005). In Europe, there are 2000 medicinal and aromatic plant taxa that are used on a commercial basis, of which approximately 70% are native to Europe, and 60% of plants are mainly imported from Asia and Africa (Lange, 1998). The loss of biodiversity, say as a decrease in the diversity or population sizes of medicinal plants, has adverse health effects. In particular, when a species goes extinct, a unique ingredient used for the treatment of cancer could be lost (Heal, 2004).

Wildlife is also an important source of food to many communities. World forests supply some or all of the food to 300 million people (FAO, 1996). Forest foods are sources of essential vitamins, minerals, carbohydrates and protein. Bush foods including the edible wild mammals, reptiles, birds, and insects, can provide up to 85% of the protein consumption of the forest dwellers (FAO, 1996). In Canada's Northwestern Territories, the Inuit consume on average approximately 200 kg per year per person of wildlife meat (Roe et al., 2000). Besides direct nutritional contributions, forest foods also add variety and taste, and encourage children, in particular, to eat more in order to meet their body needs (FAO, 1995). Forest foods can also be used as drinks or snacks. If access to the forest food source is limited, it can bring about serious consequences for health (Rijsoort & Pater, 2000). In addition to forest foods, capture fisheries and aquaculture supplied 6.6 billion people in the world with about 110 million tonnes of food fish in 2006 (FAO, 2009b). As more than 1 billion people are undernourished all over the world in 2009, the biggest number since 1970 (FAO, 2009a), the wildlife food source remains important to many people.

More than two billion people are currently dependent on wood energy, particularly in households in developing countries (FAO, 2009c). In the next decades, wood is likely to remain an important energy source in Africa and the number of people dependent on wood energy is expected to grow (FAO, 2008). In Asia, total per capita energy consumption lies between 1 to 50 gigajoule per person and wood energy consumption ranges from 2 to 10 gigajoule per person annually (FAO, 1997). Wood also can be used as furniture, construction materials, farm tools, household baskets, sleeping mats, pillows, sponges and brooms (Arnold, 1995).

Finally, it is estimated that about 300 million people, 60-70% of which are in developing countries, live in or near forests and earn part or all of their livelihoods from forests (Pimentel, McNair, Duck, Pimentel, & Kamil, 1997). People can make their living from collecting, processing and marketing forest products. In many African countries, people are dependent on hunting as a source of income (Rijsoort & Pater, 2000). Beside forest-related job and income, 47.5 million people earn their livelihoods, directly or indirectly, from primary production of fish either in capture from wild or in aquaculture (FAO, 2009b).

In summary, biodiversity is important to human well-being for many reasons, and thus, it is worthwhile to protect biodiversity. This leads to the tasks of measuring and valuing biodiversity for conservation purposes. This information is useful for quantifying and incorporating biodiversity into the optimization models.

2.3.2 Biodiversity measurement

There are a number of reasons why measuring biodiversity is not an easy task in practical terms. In its definition, biodiversity compounds the difficulty for quantifying the biodiversity of an area. Biodiversity can be measured at different scales, genes, species or ecosystems; nevertheless, the boundary of a species or an ecosystem is not clear (Gaston & Spicer, 2004). Further, there is a problem of considering multiple levels of biodiversity simultaneously. Biodiversity of wheat and corn fields, gardens and pastures is low if considered at species level, but may be high if considered at ecosystem level. While both levels are valid and important components of the measurement of biodiversity, it is difficult to draw a conclusion about the level of biodiversity present using these units of measurements (Perlman & Adelson, 1997).

In addition, while species richness is commonly accepted as a measure of biodiversity (Pearce, Moran, & Biller, 2002), to define individual species is difficult. Geneticists use DNA or the genetic codes to identify species; however, many species share a lot of common genes, for example, humans, chimpanzees and gorillas have at least 98% genes in common and only 0.6% nucleotide sequence divergences are recorded between human and chimpanzee (Cargill et al., 1999; Pearce, et al., 2002). Thus, differences in DNA are not suitable means for identifying a species.

The difficulty in measuring biodiversity also results from our lack of knowledge and information. Most species are in fact undescribed and unknown. We only know about one million described insects out of ten millions (Gaston, 1991). Only 1.4 million species, ranging from mammals down to bacteria and viruses, have been described (Wilson, 1988), out of an estimated pool of 30 million species (Gaston, 1991). Of the species that are described, most of these are unknown at a genetic level (nor is their ecological function known).

Another difficulty in measuring biodiversity is that more biodiversity is not always better, that is the biodiversity function is not monotonic. The *Impatiens wallerana* species brought from South East Asia to Costa Rica for ornamental purpose increases total biodiversity score, that is species richness, but it is not considered to have a positive contribution to biodiversity (Perlman & Adelson, 1997). Another example is the European purple loosestrife (*Lythrum salicaria*), which was also brought to US as an ornamental plant. This alien plant species has reduced the biomass of 44 native plants and endangered wildlife that are dependent on those native plants and costs $45 million per year in control costs and forage losses for the US (Pimentel, Zuniga, & Morrison, 2005).

In conclusion, the multi-dimensions of biodiversity, our lack of knowledge and information, and the positive and negative impacts of a species to humans make biodiversity measurement difficult in practical terms. This measurement problem is also the main issue that makes valuation of biodiversity so difficult and this is discussed in the next section.

2.3.3 Biodiversity valuation

Biodiversity valuation refers to a process of assigning a value to biodiversity. The term "value" represents a fundamental good that people pursue over an extended period, an ultimate reason for people's action, a quality or a practice that gives worth or goodness (Lacey, 2005, p23). This section describes the difficulties facing and the arguments against biodiversity valuation, and the shortcomings of valuation methods.

The difficulties facing biodiversity valuation come from knowledge and information problems. Since we do not know the exact number of species existing on the planet (Adis, 1990), it is hard to estimate the total value of biodiversity if the total value is assumed to be a sum of the economic value of all species. Practically, biodiversity often focuses on animal species, especially mammals. Economic valuation studies of a single species show that 64% of them focused on mammals, 23% on birds, and only 1% on reptiles and crustaceans (Martin-Lopez, Montes, & Benayas, 2008).

However, we cannot ignore the values of non-iconic organisms that we can hardly observe but contribute immense value to the ecosystem. What weight should be assigned to the mycorrhizal symbiosis that contributes to the lives of many plants and to the tiny, threadlike fungi in the soil that make those contributions possible (Ehrenfeld, 1986)? Fungi play a essential role in the evolution of terrestrial life, ecosystem function and biodiversity maintenance, human progress, and the operation of Gaia[8] (Hawksworth, 1991). Thus, the importance of these micro-

[8] "The **Gaia** hypothesis is an ecological hypothesis proposing that the biosphere and the physical components of the Earth (atmosphere, cryosphere, hydrosphere and lithosphere) are closely integrated to form a complex interacting system that maintains the climatic and biogeochemical conditions on Earth in a preferred homeostasis" (Wikipedia, 2009)

organisms cannot be ignored. Nevertheless, it is impossible for policy makers to make a decision regarding biodiversity if all micro-organisms are taken into account (van Kooten, 1998). Moreover, the value of biodiversity is more than the sum of its parts. Even if we could know the exact number of species and be able to assign a value on all species, the value of biodiversity is not merely a sum of all species' value (B. Norton, 1988).

Another knowledge and information problem is that valuing biodiversity is hard since we do not know species populations, their distributions and their roles in ecosystem services. Lack of knowledge may lead to poor conservation decisions. For instance, the US Fish and Wildlife Service spent one fourth of its 1990 budget to save Florida's ducky seaside sparrow. When the Florida species went extinct, DNA tests failed to distinguish this species from other Atlantic coast subspecies of seaside sparrows (van Kooten, 1998).

Even if all species are described, it is still hard to assign a weight to each species in order to identify its worth. For example, the tuatara (*Sphenodon punctatus)* is a large, iguana-like reptile that resides in New Zealand. It is the last survivor of the Sphenodontida, all the members of its order are lost (Perlman & Adelson, 1997). Its closest living relatives are the 6000 species of lizards and snakes that form the order Squamata. Thus, the tuatara is very high in terms of genes. However, if we consider all species as equally important, in this regard, the tuatara is no more worth than any other among 6000 species of reptiles.

There are also some arguments that go against the valuation of biodiversity since valuation implies that we can compare biodiversity preservation with the cost of doing so and in some cases decide against biodiversity preservation if the costs are too high. The ethical issue here is that from an intergenerational equity point of view we should not value biodiversity on the basis of benefit – cost comparisons today but pass on to our children, grandchildren, and great grandchildren a world which has at least the same variety of the natural resources as we have today. We can calculate the value of lost fisherman days when streams are badly polluted, but it is difficult to assign a value to the loss to society when its future generations can never experience the streams in their environment as amenities (Ehrenfeld, 1986).

The second one is that species have moral value and their value does not depend on any uses to which we put on them (Norton, 1988). Biodiversity is valuable in and of itself, and it cannot be measured relative to other things (Bann, 2002).

Thirdly, relying heavily on economic valuation may lead to a wrong conservation decision. For example, according to an economic calculation, the Japanese fisherman should kill every blue whale left in the oceans as soon as possible and then grow them rather than to wait for the species to recover to the sustainable point (Clark, 1973).

Finally, it is argued that species do not exist independently, they have coevolved in ecosystems on which they are dependent. It implies that if any action causes the extinction of any species we should also take into account the loss of its dependent species in the future. Hence, the total value of a species should include the value of all other interdependent species (Norton, 1988). The total value of a species, in this regard, seems to be impossible because of our limited knowledge in ecosystems.

In spite of the difficulties and the opposition to valuation, many efforts have been made to value biodiversity using stated preference approaches. These studies usually focus more on natural forests and wetlands than on planted forests. The most suitable techniques for valuing biodiversity so far have been contingent valuation methods (CVM) and choice modelling. Both techniques have similar limitations in biodiversity valuation, thus, the study presents the discussion with regard to the limitations of CVM.

A CVM survey contains a hypothetical market or referendum for respondents to state their willingness to pay for conservation of a specific species. The structure of the hypothetical market includes the description of the species, its habitat, and population (Loomis & White, 1996).

As mentioned above, we only know the names of 1 out of 10 species worldwide, not to mention their ecosystem services, evolutionary potential or their pharmaceutical use, CVM is, therefore, only appropriate for high profile species. This lack of knowledge poses a major obstacle to valuation using CVM. To date the most reliable studies on valuing biodiversity are those valuing high profile species or elements that are familiar to respondents (Bann, 2002; Martin-Lopez, et al., 2008).

Additionally, biodiversity valuation using CVM is influenced not only by measurement of benefits, payment vehicle, elicitation format, and timing of payment of the CVM technique, but also by the public's attitudes toward biodiversity. Species that are genetically close to humans, such as chimpanzees and gorillas, are likely to get higher willingness to pay values than dissimilar species. Species that are recognized by the respondents as being useful or beneficial to humans are more quickly protected than those perceived as useless or detrimental (Martin-Lopez, et al., 2008).

Locals who live around wildlife often have different values to people who live in the cities. Even rural people and urban residents in the same region can have different views about the values of wildlife. For instance, a survey about Asian elephant conservation shows that farmers value historical, cultural and religious values while urban people give more weight to the altruistic, bequest, and existence values of the elephant. Some farmers expressed negative attitudes toward elephant conservation because of crop damage by elephants (Bandara & Tisdell, 2003).

More importantly, the CVM approach does not appear to address the problem of irreversibility. Once our decisions cause the extinction of species, we will not be able to bring the species back. One can argue that conservation decisions are made under uncertainty, we only know the life characteristics of only small percentage of species on the planet. Thus, it is not fair to refer to this level of ignorance merely as "uncertainty" (Norton, 1988). CVM provides useful insights into the values people assign to wildlife in general, however, its information turns out not to be very useful for policy analysis (Eiswerth & van Kooten, 2009). This is because simply knowing that people are willing to pay a large amount each year to protect a species says nothing about whether one should manage habitat to protect or enhance the species' numbers.

In conclusion, measuring biodiversity is not an easy task, nor its valuation. However, to recommend any conservation policy, policy for planted forests in particular, we still need to find our way to quantify biodiversity and internalize it into a forest economic model. The next section discusses how forest management influences biodiversity in a forest as a background for quantifying and internalizing biodiversity into an economic model.

2.3.4 Forest management and biodiversity

It is well known that natural forests are rich in biodiversity. Planted forests, however, are man-made systems and are normally perceived as lacking biodiversity. This section provides evidence for the presence of biodiversity in planted forests. Then it discusses how biodiversity can be enhanced through the application of forest management practices. Finally, the section explains the use of long rotation as a method to promote biodiversity in planted forests, since this study focuses on the optimal rotation age of a forest.

There is abundant evidence that planted forests can provide a habitat for a wide range of native forest plants, animals, and fungi. There is a surprisingly high number of primary forest species living in exotic tree plantations across the world (Barbaro, Couzi, Bretagnolle, Nezan, & Vetillard, 2008; Brockerhoff, Ecroyd, Leckie, & Kimberley, 2003; Lantschner, Rusch, & Peyrou, 2008). It has been found that native beetle communities in mature plantations are very similar in composition to those in native forest in New Zealand (Pawson, Brockerhoff, Meenken, & Didham, 2008). Therefore, planted forests can provide important conservation services that are complementary to natural forest areas (Barlow et al., 2007).

Biodiversity in planted forests can be enhanced through changes in management practices (Franklin, 1993). Planted forests that are left uncut for a long time can have similar patterns of species diversity and species richness as natural forests (Sax, 2002). Planted forests with long rotation intervals may differ little in habitat value from the surrounding natural forests (Keenan, Lamb, Woldring, Irvine, & Jensen, 1997). Older stands provide a more suitable habitat for forest species than young stands (Brockerhoff, et al., 2003; Donald, Fuller, Evans, & Gough, 1998). Forests that were established on degraded or deforested areas can contribute positively to biodiversity conservation (Moore & Allen, 1999). The variability of environmental conditions and the spatial configuration of habitats are strongly correlated with plant species richness in mountainous area (Dufour, Gadallah, Wagner, Guisan, & Buttler, 2006). Species richness is also related to temporal changes in the structure of the dominant trees' canopy and geographical differences (Brockerhoff, et al., 2003).

Lindenmayer and Franklin stated that "the use of long rotations can have direct and significant consequences for biodiversity conservation at both landscape and stand levels" (D. Lindenmayer & Franklin, 2002, p. 192). Longer rotations reduce the rate of timber harvest over a given planning horizon, which is powerful in easing some of the negative impacts of short rotations while still continuing to obtain forest products from a landscape (Curtis, 1997; Moning & Muller, 2008; Thiollay, 1997). In addition, using simulation, Carey, Lippke and Sessions (1999) showed that longer rotations result in fewer clear-cut areas per decade, and thus contribute to the succession of species which is sensitive to the proportion of recently disturbed landscapes (Økland, 1996).

Further, increasing the rotation age allows more time for organisms to become re-established after clear-cut and provides a habitat for species that depend on old-growth forests, such as large-diameter trees, large snags and logs (Brockerhoff, et al., 2003; Curtis, 1997; Donald, et al., 1998). Curtis (1997) argued that a variety of age classes facilitate taxa dependent upon late-successional forest conditions and those sensitive to the effects of logging operation, thus contributing to the landscape-level heterogeneity. Additionally, longer rotations can contribute positively to enhancing biodiversity by improving connectivity between patches of late-successional forest (Franklin, Berg, & Tappeiner, 1997; Koskela, et al., 2007b; Norton, 1999).

On the other hand, it is claimed that long rotations at harvest time have negative effects on biodiversity. This is because some structural elements and related species and processes are completely lost from harvested stands or significantly reduced in percentage over the whole landscape (Lindenmayer & Franklin, 2002). This limitation, however, applies to short rotations as well, and can be overcome by keeping retention trees or promoting structural complexity (Lindenmayer & Franklin, 2002).

2.4 PUBLIC POLICIES FOR FOREST MANAGEMENT

Forests, as we have seen, generate many environmental benefits, beyond timber production, such as biodiversity provision, carbon storage, scenic values, and watershed protection. These benefits often come in the form of public goods, the benefits of which are freely available to all and forest owners are not compensated for supplying those benefits. At the same time, forest owners who allow damage to forests, and hence reduce their supply of offsite benefits, are rarely penalized

(Powell, White, & Landell-Mills, 2005). These, to society, other than timber benefits, are therefore often neglected in the decision making of private forest owners. For example, private forest owners are not likely to attempt to improve biodiversity, such as having more birds, in planted forests. Even though maintaining or enhancing species, through delayed harvesting or maintaining forest, benefits society, it results in a loss in timber profit for forest owners. Ignoring forest benefits can make the private optimum use of resources diverge from the social optimum.

In the above example, a social optimum for forest harvest with more birds in planted forests calls for a longer rotation age. Unfortunately, private forest owners do not seem to let their trees grow longer unless there are incentives or regulations or other mechanisms encouraging them to do so. If society desires to bring a private optimum in line with a social optimum, then public policies need to be put in place. The next section presents definition and classification of public policies, and a review of policy tools for forest management.

2.4.1 Definition and classification of public policies

Public policy tools or instruments are the underlying method or approach used to achieve a policy objective by a government (Salamon & Lund, 1989). Public policies aim to get a change in behaviour or activity that might not otherwise be changed in order to implement the desired behaviour (Schneider & Ingram, 1990). There are various frameworks and classification schemes to describe public policies (Schaaf & Broussard, 2006). Based on behavioural assumptions associated with policy tools, policy tools can be divided into authority, incentive, capacity-building, symbolic/hortative, and learning (Schneider & Ingram, 1990).

Authority tools refer to regulations that permit or prohibit the behaviours of target populations. Incentive tools rely on providing tangible payoffs for people to engage in the desired behaviours by assuming that people will take advantage of opportunities in order to maximize their gains. They are initiated to adapt to current economic, political, and resource conditions. They also focus more on multi-functional forestry elements, such as non-market values, social criteria, collective and public goods, and face increasingly limited government budgets (Cubbage, Harou, & Sills, 2007). Capacity tools provide education and training to motivate people to behave in the manner desired. Symbolic and hortative tools are based on the assumption that people are encouraged from within and behave in ways that are consistent with their beliefs. Learning tools are flexible and adaptive with regard to their purposes or objectives and assume that people can select suitable policy tools through learning and cooperating.

With the emergence of new policy instruments, public policy tools can also be described as traditional and contemporary instruments (Cubbage, et al., 2007; Sterner, 2003). A review of policy tools for forestry management including regulations, education, subsidies/taxes, and new market approaches follows.

2.4.2 Regulations

Regulations are policy tools aimed at restricting behaviours of target populations. Regulations in forestry can be in the form of clear-cut size, allowable cut constraints, stream buffers, road protection, and reforestation requirements (Cashore & McDermott, 2004). Regeneration regulations are popular in developed countries, while the "allowable cut" is widely applied in developing countries. The latter regulation permits a certain volume of timber to be extracted from a forest during a set period of time (Sterner, 2003). Sometimes, rotation lengths are regulated, up to a hundred years in temperate forests. Moreover, regulations that limit timber cutting can be applied to protect red list species. For instance, in US, the Endangered Species Act (Paillet et al., 2010) is imposed on family forest owners to protect the listed threatened and endangered species as well as their critical habitats (Zhang & Flick, 2001).

The success of regulation worldwide significantly correlates with income per capita, security of property rights, and general development of the legal and regulatory system (Dasgupta, Mody, Roy, & Wheeler, 2001). Forest regulations are designed in an attempt to reduce social costs resulting from the way private forests are currently managed. They can also be used to reallocate the costs of biodiversity conservation from state agencies to private owners as the latter can manage the resources at lower costs (Moyle, 2003). Over-regulation of private forest management, however, can lead to bad consequences (Laarman, 1997). For example, over-regulation may result in too much investment in forests that goes beyond the margin of social efficiency, such as in Europe (Turner & Wibe, 1992). It may also lead to avoidance, fraud, and injustice, such as in Costa Rica (Laarman, 1997). For instance, Costa Rica allows a private forest owner to cut a maximum of ten trees with a single permit for a forest area. This, however, encourage the owner to divide their land into small parcels to obtain multiple permits. In response, the Costa Rica government requires landowners to have management plans for even a small parcel, and have to apply for permits to cut the trees specified in their plans. This process, however, is very expensive for landowners, and thus, trees are cut illegally at many forests.

2.4.3 Education

Education includes general public education and professional education (Lazdinis, Carver, Tõnisson, & Silamikele, 2005). Professional education benefits future generations, but does little in raising the awareness and changing behaviour of general populations (Sutherland & Ham, 1992). With regard to general public education, environmental programs can play an important role in demonstrating how people activities influence the environment and in encouraging local communities to take collective responsibility for their actions (Ralambo, 1994). Moreover, Day and Smith (1996) suggested that environmental education that provides community members with cognitive tools and practical behavioural experience can change community environmental behaviour.

Specifically to the forestry sector, education is the most popular tool employed to encourage loggers and foresters to apply sustainable harvesting practices in developed countries (Kilgore & Blinn, 2004). Educational policy tools could be used to encourage landowners to manage their forests in a sustainable way (Janota & Broussard, 2008), since they promote participation from landowners.

However, education programs are not effective in changing behaviour in forest management in developing countries (Naka, Hammett, & Stuart, 2000). Conservation education programs normally have been fairly effective in raising awareness among the local communities with regard to the importance of conservation, but ineffective in influencing attitudes towards conservation and the conservation practices of the local people (Byers, 2000; Oonyu, 2009).

2.4.4 Subsidies and taxes

Subsidies can come in the form of free seedlings, management assistance, or financial aid for management (Sterner, 2003). Subsides have been popular in developed countries, such as Europe and the United States, to promote timber supply for the mill industry and for heating. Subsidies for reforestation can also take the form of tax incentives, cost reimbursements, and other mechanisms. Subsidized private reforestation has been a common application in Brazil, Chile, Colombia, Ecuador, and Costa Rica (Laarman, 1997). In developing countries, subsidies, in the form of free seedlings, have failed since they did not consider the discount rates of local people (Sterner, 2003). When the discount rates are high, subsidies may have little effect on tree planting. Moreover, it is claimed that the subsidies for planted forests may lead to economic distortions and even environmental degradation (Bull et al., 2006). According to Bull et al. a subsidy for establishment cost, in particular, can encourage plantations in the beginning but can be misused later. For example, forest farmers may use strategies to plant poor quality trees or claim for non-existent forests to get money from subsidies.

Taxes are applied mostly to privately owned forests to catch a share of scarcity or land rent, or to avoid or correct externalities generated. Taxes can be enforced on land, standing timber, or harvested timber (Sterner, 2003). For example, private forest owners in Latvia have to pay land and property tax (Lazdinis, et al., 2005). The effective issuance of land taxes requires substantial public expenditure to improve land titling, registration, and valuation methods and needs to deal with opposition from both large and small landowners (Laarman, 1997). Moreover, taxes on land can encourage harvesting timber earlier than optimal and converting forest land to other land uses (Sterner, 2003). Taxes on standing forests if not designed carefully can lead to high-grading problems, that is the extraction of only valuable trees (Sterner, 2003). Taxes on harvested timber can range from 5% to 26% from timber sales in Estonia, Lithuania, and Latvia (Lazdinis, et al., 2005).

2.4.5 Direct payments

Biodiversity provision is a collective good that has no direct economic value to the provider (Cubbage, et al., 2007), or, in other words, its provision is not paid for. In this context, market approaches are suggested to be suitable policy tools for biodiversity conservation because it is thought that capturing the financial value of forest services will promote good stewardship and discourage more degrading uses of forests (Milne & Niesten, 2009; Powell, et al., 2005). Market approaches have gained prominence over regulatory approaches since the latter are often thought to be inefficient, expensive and inequitable (Powell, et al., 2005). However, market approaches also face many challenges. In particular, market performance depends on numerous site-specific factors, including existing power relations, degrees of concentration in demand and supply, the supply of information on trading conditions, and the level of transaction costs (Powell, et al., 2005). Market mechanisms and new market approaches for forest management can take a variety of forms and vary according to their particular ecological, social and political contexts (Powell, et al., 2005). They include direct payment, payment for environmental services (PES), forest certification, biodiversity offsets, integrated conservation-development projects (ICDPs), and other mechanisms.

Direct payment is a contractual mechanism in which local resource users are compensated for provision of biodiversity (Milne & Niesten, 2009). Direct payment can be used to compensate people for maintaining biodiversity, and compensate individuals living near threatened ecosystems since they will have limited or no access to the resources (Ferraro, 2001; Milne & Niesten, 2009). Direct payments can also serve as a mechanism to conserve corridors and buffer zones that are not formally protected (Milne & Niesten, 2009). One main feature of direct payments is that the payment to the local resource owners for the provision of biodiversity is conditional. If the providers do not comply with the conservation contracts, for example, failure to deliver the conservation services as stated, then the payments will be withdrawn.

Direct payments have been used widely in developed countries to conserve biodiversity; however, its application in developing countries is limited (Wunder, 2006). Up to now, there have been a total of 48 cases of direct payment schemes for biodiversity services in developing countries, such as Ecuador, Costa Rica, Madagascar, Cambodia, China, Peru, and Venezuela (Milne & Niesten, 2009). These payment schemes are at least partially funded by international agencies and target the protection of habitats and forests. They can be annual renewable contracts based on conservation performance, or contracts for a certain period, such as 100 years. Nevertheless, direct payments have the potential to resolve the complexities of conservation in developing countries and to increase the effectiveness and efficiency of conservation investments (Milne & Niesten, 2009). Direct payments are “the cheapest way to get something you want” (Ferraro, 2001, p. 1719).

There are, however, concerns about the feasibility, sustainability, and potential social impacts of direct payments (Milne & Niesten, 2009). Regarding feasibility, direct payments are not sustainable in the long term, since when the payments stop, because of budget constraints for example, the provision of conservation services becomes uncertain (Swart, 2003). Concerning sustainability, direct payments do not seem to be helpful in building local management capacity or allowing people to organise themselves to engage in broad environmental protection (Hutton, Ada, & Murombedzi, 2005).

Regarding social impacts, there is a concern regarding equity and ethical issues given the asymmetric interactions between international conservation organizations (who have money) and local institutions in developing countries (who depend on funding). This could lead to a possibility of treating societal assets in these countries as private assets (e.g. exclusion of rural people from exploiting the resources they need), and hence, distorting the values of these resources (Hutton, et al., 2005 ; Romero & Andrade, 2004). Another social impact is that the establishment of direct payment to conserve biodiversity also blocks the free access to vital livelihood resources like water, fuel wood and traditional medicinal plants (Lovera, 2005). Finally, commercial conservation may "erode culturally rooted not-for-profit conservation values" (Wunder, 2006).

Additionally, direct payment approaches also face many difficulties in practice, which are particular to them or arise from conditions present in developing countries (Milne & Niesten, 2009). There are difficulties related to institutional arrangements, and establishment and maintenance of legal, political and social conditions. Conditions in developing countries include weak governance, poorly secured property rights, limited human capacity, and conflicts between conservation and human development.

Despite these challenges, direct payments show potential as a tool for engaging local communities or resource users in conservation and as a mechanism for channelling global investments in biodiversity conservation services to site-based initiatives (Cubbage, et al., 2007; Katila & Puustjärvi, 2004; Wunder, 2005).

Normally, the amount of payment equals the opportunity cost of conservation (Cubbage, et al., 2007; Katila & Puustjärvi, 2004).

2.4.6 Payment for environmental services

Payment for environmental services (PES) is a voluntary transaction in which an environmental service is purchased by at least one buyer from at least one provider (Wunder, 2006). The introduction of PES related to biodiversity protection and carbon sequestration offers considerable promise for reducing deforestation and compensating local forest owners (Pagiola, Bishop, & Landell-Mills, 2004). PES can take many forms, such as conservation easements, conservation concessions, and tradable development rights (Wunder, 2006). Conservation easements refer to compensated permanent caps on individual land-development rights and have been widely used in developed countries. Similarly, conservation concessions are compensated time-bound caps on land development and often apply to forests. Under conservation concessions, forest owners are only paid for the loss of revenue from not exploiting their resources, not for the lost jobs and tax revenue. Tradable development rights permit individual agents to buy or sell their individual land development allowances, and have been applied in both developed and developing countries.

Another tool to pay developing countries for reducing carbon emissions (and biodiversity conservation) is REDD (Reduce Emissions from Deforestation and Forest Degradation). REDD is a mechanism to encourage carbon sequestration after the period of 2008-2012 via payment for forest owners in developing countries to keep their forests standing (UNFCCC, 2011). Going beyond deforestation and forest degradation, “REDD+” considers the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. REDD is not included in this research because of the following reasons. Firstly, REDD’s main target is to avoid deforestation and forest degradation in natural forests, while my thesis deals with planted forests. That is, REDD tries to preserve forests totally, while this study addresses delaying harvest for a short period of time. Secondly, REDD's mechanism is to reward the whole nation not the individuals who own forests, while my thesis focuses on policy implications for individual forest households. Funding for REDD can come from developed country donors, corporations, nongovernmental organizations, and individuals (Phelps et al 2010). However, there is still no consensus about payment mechanisms to developing countries (Angelsen, 2009). An example of payment mechanisms is that developing countries will build their national REDD implementation plans in order to request for international funding. This funding if it eventually reaches individuals in developing countries, is money paid for protection of forests (i.e., keeping natural forests standing), not for production of forests (i.e., planting trees) in the case of Vietnam since individuals do not own natural forests. Thirdly, REDD faces a lot of criticisms with regard to how to define payment mechanisms, deforestation baselines, forest degradation concepts, and how to get funding (Van Dam, 2011). Thus, there is a great uncertainty about whether REDD will be implemented after the year 2012.

2.4.7 Forest certification

Forest certification is a more recent development and seeks to ensure that economic, social, and ecology criteria are considered in the management of forests. There are several internationally recognized certified bodies, such as Forest Stewardship Council (FSC) and The Canadian Standards Association (CSA).

There is evidence that forest certification can contribute to biodiversity conservation in managed forests through changes in management practices (Gullison, 2003; Thornber, 1999). For example, the FSC Principles and Criteria contain management prescriptions that benefit biodiversity; thus, the process of FSC certification requires companies to make changes to management that would benefit biodiversity (Gullison, 2003). Forest certification provides a means by which producers who meet sustainable forestry standards can potentially receive greater market access and higher prices for their products (Gullison, 2003). This is because there is strong preference by respondents toward certified printer paper (Kruger, 2010). Further, premium prices are claimed to be one of the most efficient programs targeted at loggers to sustainably manage their forests as their benefits exceed their investment costs (Kilgore & Blinn, 2004). According to FSC (FSC, 2010), forest certifications encourage consumers and businesses to make purchasing decisions that benefit both the environment and the business values. The FSC is established in 50 countries and has certified 129.35 million ha of forests over the world (FSC, 2010).

2.4.8 Biodiversity offsets

Biodiversity offsets are a compensation mechanism for residual environmental impacts of project development by the investor, after appropriate steps have been taken to avoid and minimize impacts on site (ten Kate, Bishop, & Bayon, 2004). Offsets most often seek to create new habitats, but can preserve existing habitats where there is currently no protection (Norton, 2009). Biodiversity offsets, also known as mitigation, have a great potential as a powerful tool for achieving the dual goal of conservation and development (McKenney & Kiesecker, 2010).

Biodiversity offsets have been widely used in developed countries, such as the United States, Australia, Brazil, Colombia, South Africa, Netherlands, Sweden, and United Kingdom, to protect both species and ecosystems. Offsets offer potential benefits for industry, such as greater societal support for development projects; for government, such as encouraging companies to make significant contributions to conservation; and for communities affected by development projects, such as gaining additional conservation benefits in the surrounding area (ten Kate, et al., 2004).

In spite of their great benefits, the establishment of biodiversity offsets faces a number of conceptual and methodological challenges (Kiesecker et al., 2009). It is claimed that most of the approved offsets have failed to meet their objectives or never actually occur, especially in North America (Norton, 2009). Biodiversity offsets are not suitable for some types of ecosystems, such as ecosystems where the clearance of them would result in the species' extinction (Gibbons & Lindenmayer, 2007). Biodiversity offsets are also inappropriate when there is a significant lag between habitat loss and replacement of resources for a threatened species; because offsets are unable to achieve no net loss in the medium-term, the temporary loss of biodiversity can cause the extinction of species (Maron, Dunn, McAlpine, & Apan, 2010). The issue of uncertainty is also raised when considering the application of biodiversity offsets because the immediate loss of species or ecosystems is certain, whereas future gain is uncertain (Moilanen, van Teeffelen, Ben-Haim, & Ferrier, 2009).

2.4.9 Integrated conservation-development projects

It is apparent that biodiversity loss and poverty have a linkage and that conservation and poverty reduction should be addressed together (Adams et al., 2004). Integrated conservation-development projects (ICDPs) attempt to enhance the management of protected areas through improving the standard of living of adjacent residents and are normally sponsored by international funding agencies (Laarman, 1997). These projects include ecotourism, wildlife farming, and bioprospecting among others.

Ecotourism generates more income with significantly less environmental impact, than that caused by other forms of direct exploitation of natural resources, such as the timber or cattle industries (Gámez, 2007). The market for nature-based tourism and associated forest-based services is large and expanding (Katila & Puustjärvi, 2004). For instance, ecotourism and bioprospecting have contributed substantially to economic achievements of Costa Rica (Gámez, 2007). Forests provide many services contributing to the development of nature-based tourism and recreation. Outside protected areas, hunting leases are a significant source of revenue for forest landowners in some regions, and can reach 5 to 100 USD per hectare in USA (Katila & Puustjärvi, 2004). Further, the rapid expansion of bird watching and other forms of wildlife tourism throughout much of the world is making a substantial economic contribution for local communities in apparently environmentally-friendly ways (Green & Jones, 2010; Hvenegaard, Butler, & Krystofiak, 1989). Such tangible benefits are providing sound incentives for protection of landscapes and species, especially when threats are derived from alternative resource uses that are traditionally measured in the marketplace, such as timber (Hvenegaard, et al., 1989).

Beside ecotourism, wildlife farming, butterfly farming in particular, is also a form of ICDPs. Butterfly farming is an important facet of promoting habitat conservation in tropical regions (New, 1994). One example is the Kipepeo Project, a community-based butterfly farming project on the margins of Arabuko-Sokoke Forest on the north coast of Kenya. This forest is a globally important forest for biodiversity conservation. In the effort to protect the forest, farmers living next to the forest were trained to raise butterflies, and their products, butterfly pupae, were purchased for export to the live butterfly exhibit industry in Europe and the United States (Gordon & Ayiemba, 2003). The project has significantly positive effects on both livelihoods and attitudes, and has no adverse effects on wild butterfly populations (Gordon & Ayiemba, 2003).

Finally, bioprospecting refers to the search for genes, compounds, designs, and organisms that might have a potential economic value or lead to the development of a product (Tamayo, Guevara, & Gamez, 2004). A well-known example of bioprospecting is the contract signed in 1991 between INBio (the National Biodiversity Institute created by the government of Costa Rica) and the pharmaceutical corporation Merck & Co. (USA) regarding the benefit sharing mechanisms of any development from biodiversity resources. Costa Rica is a country with a rich biodiversity in natural forests (Gámez, 2007). Under this agreement, INBio would supply Merck with samples of plants, insects and micro organisms collected from Costa Rica's protected forests. Merck then would have the right to use these samples to create new pharmaceutical products (MERCK, 1991). The Merck contract with both domestic and international parties provides partial solutions to public goods problems and brings in rents from genetic resources which are reinvested in the production of public goods (Meyer, 2008).

However, there is increasing concern that global efforts to protect biodiversity are not in line with those to reduce poverty (Sanderson & Redford, 2003). The creation of protected areas can have significant negative impacts on local people, such as the exacerbation of poverty, the contravention of legal rights, and the infringement of human rights (Adams, et al., 2004). Further, ICDPs that attempt to integrate conservation and development are claimed to be overambitious and underachieving (Adams, et al., 2004). It is argued that bioprospecting, ecotourism, and other forms of ICDPs alone are inadequate to relieve the local pressure on tropical forests, and that ICDPs have not worked well in protecting biodiversity in developing countries (Simpson, 2004). It is suggested that developed nations who value biodiversity in developing countries must work out property rights and make direct payments to achieve forest conservation and biodiversity (Simpson, 2004).

2.4.10 Other policy tools

Forest concessions and timber contracts (with conditions on harvest volume per period or harvest age) are the forest policy tools with which governments grant private companies permission to extract timber from large forests owned by governments. These types of instrument can encourage sustainable forest management and efficient harvesting and avoid illegal logging; however, they often apply to natural forests (Sterner, 2003).

In the United States, forest banking has been applied to environmental preservation on privately-owned forestlands (Janota & Broussard, 2008). The Forest Bank program requires landowners to deposit their right to grow and manage timber on their land in exchange for guaranteed annual dividend payments (Janota & Broussard, 2008). Best Management Practices (BMPs) have been used in many states in the U.S to ensure that forest practices and harvesting do not cause undue harm to the environment. BMPs are often implemented in concurrence with voluntary educational programs (Janota & Broussard, 2008).

In Finland, METSO, a program that relies on a graduated compensation system for landowners based on forest revenue and conservation value, has been instituted to protect biodiversity on private lands (Horne, 2006). This program uses different payment schemes to compensate for forests based on their biodiversity values (such as decayed wood and large aspen trees). Other tools include international sustainable forest management, protection, government ownership, market sales, and production, and clarification of property rights.

In conclusion, selection of a policy tool depends on economic, social, and cultural conditions of the target population, and the purposes that the government wants to achieve, e.g. preservation of a whole forest or lengthening rotation.

2.5 SUMMARY

The determination of the optimal rotation age, for both single and multi-stand forests, when only timber value (hereafter called timber rotation age) or both timber and carbon values (hereafter called carbon rotation age) are included has been well documented in the literature. The literature shows that the carbon rotation age may differ from the timber rotation age. In Vietnam, optimal timber rotation ages have been identified, but not carbon rotation ages. When biodiversity conservation is considered in optimal forest management, the optimal rotation age at stand level (hereafter called the biodiversity rotation age) is lengthened compared to the timber rotation age. Further, the incorporation of spatial interactions among forest stands shows that the optimal rotation age also differs from the timber rotation age; this spatial model, however, is limited to a two-stand forest. Uncertainty can impact on the optimal rotation age but the magnitude of the impact depends very much on the assumptions made about the type of uncertainty and the underlying attitude to risk.

In conclusion, the literature has not yet identified the biodiversity rotation age at forest level and has only considered the spatial interactions and arrangements among forest stands for a two-stand forest; the carbon rotation has not yet been identified in Vietnam. This research, therefore, investigates the impacts of the spatial interactions and arrangements among forest stands to the carbon and biodiversity rotation. In this context, spatial interactions are defined as economies of scale in planting trees. This means that planting several forest stands at the same time can help reduce planting costs. In addition, sensitivity analyses will be used to determine the impact of uncertainty on optimal rotation ages.

Further examining the literature, this study finds that, up to now, no research has been conducted to determine the optimal level of direct payment to promote biodiversity in planted forests at a forest level. Moreover, biodiversity is worthwhile to preserve; and biodiversity in planted forests can be improved through changing management practice, such as the use of long rotation. Biodiversity measurement and valuation, however, face many challenges. There are many forest policy tools available for enhancing biodiversity. Selection of a policy tool, depends on economic, social, and cultural conditions of the target population, and the purpose that the government want to achieve, e.g. preservation of a whole forest or lengthening rotation.

CHAPTER THREE. METHODOLOGY

3.1 INTRODUCTION

In this chapter, the general models to be used to calculate socially optimal forestry rotations will be presented. This chapter starts with a discussion of the background for the development of the biodiversity model, including the safe minimum standard (SMS), taxa as a biodiversity indicator, the calculation of population size, and the selection of the minimum viable population (MVP). Section 3.3 describes the optimization models for timber production, carbon sequestration, biodiversity conservation, and direct payments. The optimization methods for solving the models and model data are discussed in section 3.4. Details about secondary data and the survey conducted are presented in section 3.5 and 3.6, respectively. The secondary data section describes the procedures to obtain the timber growth, carbon sequestration, and bird abundance functions in planted forests from the secondary data sources. The survey section presents questionnaire development, survey implementation, and data analysis in Yen Bai province.

3.2 SET UP FOR THE BIODIVERSITY MODEL

3.2.1 The safe minimum standard approach

To come up with criteria for biodiversity for use in an optimization model, biodiversity valuations do not appear to be a suitable approach as discussed earlier. Given our poor knowledge of the ecological role of different species and the fact that extinction is irreversible, the choice about whether or not to save a species is analysed from a game theory approach. This is also known as a cautious strategy that involves adoption of the SMS approach first introduced by Ciriacy-Wantrup (1952) as a flexible policy tool to help preserve renewable natural resources. This approach was further developed by Bishop (1978), who provided a practical tool for decision-making in situations where economic development threatens irreversible damage to the environment. The SMS approach refers to a collective choice process maintaining a minimum level of a renewable natural resource that makes it feasible for the stock to recover unless the social costs of doing so are extremely large. The SMS approach implies that preservation of an endangered species is a *priori* beneficial, but is sensitive to the conservation costs faced by society.

To describe the SMS approach, Bishop (1978) supposed that a hydroelectric dam has been proposed which would cause an endangered species to become extinct. To assist public decisions of whether to build a dam or not, Bishop proposed a game with two players, "society" and "nature". In this game, it is assumed that nature chooses its strategy by some unknown mechanisms. Thus, according to Bishop, to play against nature, it is suggested by Luce and Raiffa (1989) that the minimax loss principle should be employed, i.e. society minimizes its maximum possible losses. The matrix of losses for this game is presented in Table 3.1.

Table 3.1 Matrix of losses (Bishop)

STRATEGIES	STATES		Maximum Losses
	NO OUTBREAK	*OUTBREAK*	
SMS	B_d	B_d -L	B_d
DEV	0	L	L

Source: Bishop (1978)

As shown in Table 3.1, Bishop (1978) assumed that society has two strategies: development (*DEV*), i.e. building a dam which will lead to species extinction, and the maintenance of the safe minimum standard (*SMS*), i.e. not to build a dam. It is also assumed that, in the future, an unexpected event may occur, such as an outbreak of disease, and the species will be a cure for the disease. The game includes two states of nature *NO OUTBREAK* and *OUTBREAK*. The first state (*NO OUTBREAK*) is that extinction will not cause an excessive social loss, i.e. future outbreak does not occur. The second state (*OUTBREAK*) is that extinction imposes an extremely large cost on society, i.e. future outbreak occurs and the species turns out to have a special worth, symbolized by L. The baseline situtation for the game is *DEV* and *NO OUTBREAK*. Let B_d be the net present value of benefits from hydroelectric power generation. Then *SMS* and *NO OUTBREAK* represents a loss of B_d. Bishop assumed that both B_d and L are greater than 0. It is also assumed that the probabilities of alternative outcomes (whether an outbreak occurs or not) are uncertain but the payoff matrix, B_d, is known with certainty. Using a minimax loss rule, Bishop (1978) concluded that *DEV* should be chosen if $B_d > L$, *SMS* should be chosen if $L > B_d$, and either strategy can be chosen if $B_d = L$.

However, Bishop (1978) expressed three concerns towards the game solution. The first concern is that the minimax solution is conservative in the extreme. He explained that, according to the minimax solution, the *SMS* should also be adopted if its costs (B_d) are only slightly less than the social losses (L). However, he argued that if the costs of avoiding uncertainty (whether an outbreak occurs) are unacceptably large, society should accept the chance of large losses rather than choosing the *SMS*. Another concern is that the payoff matrix, which is assumed to be known with certainty, is not very realistic. The final issue is that the payoff matrix is static and unable to address the problem of intergeneration equity (i.e. who will receive the gains and bear the losses). Thus, he suggested that it might be suitable to apply a modified minimax loss principle for making the conservation choice of species. That is the society should adopt the SMS unless the social costs of doing so are intolerably high.

Employing the same minimax principle as Bishop (1978), Ready and Bishop (1991) developed a "lottery game" that changed the assumption of the previous game. In the lottery game, the outbreak of the disease is known with certainty but whether or not a species can be a cure for treatment is unknown. Thus, there are two states in this game. In the first state (*CURE*), the species does hold the cure for the treatment of the disease. In the second state (*NO CURE*), the species does not hold the cure. The lottery game has two strategies, *DEV* and the *SMS*, as in the game of Bishop (1978). Let B_d be the development benefits and $B_d > 0$. Let L be the possibility of future losses, which are assumed to be large to the extent that $L > B_d$. The matrix of losses for the lottery[9] is presented in Table 3.2.

[9] Ready and Bishop (1991) argued that Bishop (1978) incorrectly specified his matrix of losses.

Table 3.2 Matrix of losses (Ready and Bishop)

STRATEGIES	STATES		Maximum Losses
	CURE	*NO CURE*	
SMS	$- L$	0	0
DEV	$- B_d$	$-B_d$	$- B_d$

Source: Ready and Bishop (1991)

The baseline for the lottery game is no development and no cure. Hence relative to the baseline, as shown in Table 3.2, if the *SMS* is chosen and state *CURE* occurs, the loss from the disease is avoided, giving a net loss to society, relative to the baseline, of $-L$ (gain), i.e. $0 - L = -L$. If DEV is chosen, the loss under both states is $0 - B_d = - B_d$. Thus, the maximum possible loss under the *SMS* in this game is zero, while under *DEV* is less than zero (i.e. $- B_d$). Following the minimax principal, Ready and Bishop (1991) concluded that the development strategy is chosen for the lottery game (because it has lower maximum loss compared to that of the *SMS*).

However, using the minimax-regret decision rule by Loomes and Sugden (1982), Ready and Bishop (1991) argued that the *SMS* should be adopted for the lottery game. According to Loomes and Sugden, when making decisions under uncertainty, individuals consider regret. That is, having to choose between two actions in a situation of uncertainty, the individual "may reflect on how much better his position would have been, had he chosen differently" and this reflection may reduce the pleasure that he derives from the chosen action (Loomes & Sugden, 1982, p. 808). Thus, individuals will maximize expectation of modified utility (i.e. incorporating regret) rather than expected utility. Ready and Bishop argued that the intuitive belief that endangered species should be preserved is motivated by the regret theory, and concluded that the SMS may be "the right thing to do" from the society's viewpoint.

The SMS approach has continued to survive (Berrens, 2001). It has been discussed widely in environmental economics textbooks (Berrens, 2001; Cooney & Dickson, 2004). The approach has been applied in official public policy, such as the US Endangered Species Act, the European Union's Habitats Directive, and the inter-related Common Agricultural Policy, and appeared on the policy advisory boards (Baumgartner & Quaas, 2009; Berrens, 2001). The approach has also been applied in the real world, such as identifying habitat requirements for multiple fish species, the conservation and sustainable use of farm animal genetic resource diversity, and the integrated basin management for water and food (Drucker, 2006; Gurluk & Ward, 2009). Moreover, the SMS has been recognized in the ecology and economics literatures and can be a bridge between ecologists and economists (Tisdell, 1988; Toman, 1994).

To adopt the SMS, the estimation of the monetary benefits of conservation is not required (Berrens, 2001; Crowards, 1998). The SMS approach does not depend on the valuation of the non-market benefits of species preservation, thus it avoids the problems of biodiversity valuation. The SMS approach can also avoid the problems of biodiversity measurement mentioned above by using taxa as a biodiversity indicator, which can represent the overall biodiversity of a whole forest. This means that we do not neglect the presence of other species, and that the biodiversity of these species is reflected in the biodiversity of the selected taxa. According to the SMS's principle, the biodiversity of the selected taxa would be kept above a minimum standard to guarantee that the species will survive over a planning horizon. The selection of taxa as a biodiversity indicator and the identification of a minimum standard, which is known as a minimum viable population (MVP), are presented in the next sections.

3.2.2 The selection of taxa as a biodiversity indicator

The biodiversity of even a small area is far too complicated to be comprehensively measured (Duelli & Obrist, 2003). Measuring biodiversity requires not only identification of the explanatorily salient dimensions of diversity but also a measurement of biological systems and given the constraints on time, resources, and information available (Maclaurin & Sterelny, 2008), this is a task which is neither practical or feasible. Thus, suitable indicators have to be found to measure biodiversity instead.

Among biodiversity indicators, species diversity (species richness and species abundance) is most commonly accepted in terms of measurement and valuation (Pearce, et al., 2002) and widely applied to measure biodiversity by economists (Eppink & van den Bergh, 2007; Juutinen & Mönkkönen, 2004; Smith et al., 2008). This indicator is basic, simple (Begon, Harper, & Townsend, 1996; Magurran, 1988), has a good discriminant ability (Magurran, 1988), and is most available in terms of data (Begon, et al., 1996; Mayer, 2006). As comprehensive biological inventories of sites are unlikely to be obtained (Harper & Hawksworth, 1996), we need to look for some taxa that are particularly good indicators of overall biodiversity.

The ideal characteristics of a biodiversity indicator are that they are immediately affected by a change in harvest practices, easily monitored, taxonomically tractable, and representative of overall diversity. In this regard, animals are preferred to plants as a proxy for biodiversity, since the latter is not immediately affected by a change in harvest practices as a result of seed banks effects (i.e. seeds remaining in soils can grow in the next seasons). Among animals, two taxa that are often employed are birds (Aves) and butterflies (Lepidopterons). These groups are well documented and easy to monitor in the field (Lawton et al., 1998). Butterflies are recommended as indicators of overall biodiversity because they have an ability to resist the impact of human activities and contain the large amount of ecological information available in plants (Scott et al., 1993). Species diversity in both taxa has a strong linear correlation with the overall biodiversity of a community (Pearman & Weber, 2007).

The forest type chosen for this study is the exotic planted forest, and this forest type has both birds and butterflies (Mitra & Sheldon, 1993). For example, Daniels, Hegde, and Gadgil (1990) reported 21 bird species in *Eucalyptus* planted forests. Sheldon, Styring and Hosner (2010) showed that *Acacia* planted forests attract numerous primary forest birds, especially in mature forests. Also, Sheldon *et al.* found 56 butterfly species in tropical *Eucalyptus* planted forests.

No significant differences have been found between forests of different tree species and species abundance of birds and butterflies. Yap, Sodhi and Peh (2007) reported that the similarity in overall understory-resident bird abundance and comparative species richness between forest types is because of the similarity in food resources. Diaz (2006) studied three forest types and concluded that there is no clear difference in bird abundance among these. Moning and Muller (2008) suggested that tree species composition has an influence on a limited number of bird species. Thus data about species richness and abundance of birds and butterflies from one forest type can be used for another forest type.

In planted tropical forests, forest age and canopy closure are positively correlated. Normally, forest stands have a closed canopy from year four and onwards. There is evidence that mature and closed canopy stands increase bird species diversity and abundance (Diaz, 2006; Sheldon, et al., 2010). For example, Luck and Korodaj (2008) examined birds in exotic pine planted forests in Australia and concluded that species richness is significantly higher in mature (20 years from planting) and old (27 years from planting) stands. Hill, Eames, Trai and Cu (2001) studied population sizes and habitat associations of forest birds in natural and semi-natural forests and plantations in Da Lat, Vietnam. Their results showed that bird richness and abundance are positively correlated with canopy closure. Moreover, Moning and Muller (2008) examined forest birds in Central Europe and suggested that canopy cover and forest age are the important factors that affect bird diversity and abundance in montane forests. Similarly, Guenette and Villard (2005) suggested that canopy closure and the density of large trees (>30 cm dbh) should be at least 70% and 80 stems/ha, respectively, to expect to find the complete assemblage of bird species. Finally, Clout (1984) claimed that retaining old trees and creating a mosaic of stands of different ages are some of the ways to improve the diversity of native birds in exotic forests.

In contrast, both butterfly richness and abundance have a negative relationship with stand age and canopy closure. Barlow et al. (2008) reported that butterfly richness and abundance in *Eucalyptus* plantations were strongly affected by stand age. Spitzer et al. (1993) analysed the habitat preferences of butterflies in Tam Dao, Vietnam. They compared the abundance and diversity of butterflies in three types of land uses: ruderal, transitional, and forest zones. The ruderal zone (open canopy) refers to cultivated and abandoned terraced fields on relatively steep slopes. The transitional zone consists of clearings with scattered shrubs and clumps of trees. The forest zone (closed canopy) is a natural protected area, which is only disturbed by illegal selective logging. They concluded that a closed canopy (forest zone) has lower butterfly richness than an open canopy (ruderal and transitional zones).

Regarding forest structure and landscape patterns, it is said that even-aged and harvested planted forests can decrease bird diversity (Mitra & Sheldon, 1993). Najera (2010) showed that both bird species richness and abundance were significantly higher in complex than in structurally simple planted forests. Scott et al. (1993) suggested that birds respond more to the structure of vegetation, namely the degree of canopy closure, spacing of dominant trees or shrubs, and height of dominant trees and shrubs, than to floristic composition. In addition, Clout (1984) recommended that the creation of a mosaic of stands of different ages can attract native birds. Further, bird species richness probably depended more on landscape patterns than stand quality (Paillet, et al., 2010). Lindenmayer’s (2010) results suggested that bird species richness depended not only on the features of the vegetation within a planted forest, but also on where a forest was placed. In particular, Yamaura et al. (2009) examined the effects of forest patch size ranging from 1.4 to 312 ha on bird assemblages and found that species richness increases with a rise in patch size, especially with area greater than 40 ha. This follows from the fact that birds are good fliers and their home range sizes range from 4 to 40 ha (Mac Nally, Fleishman, Bulluck, & Betrus, 2004).

In contrast, butterflies are likely to depend more on the habitat quality of a stand than the forest structure and landscape pattern. Barlow et al. (Barlow, Overal, Araujo, Gardner, & Peres, 2007) analysed the value of primary, secondary, and plantation forests for fruit-feeding butterflies in the Brazilian Amazon and found that butterfly richness and abundance were more affected by habitat quality (i.e. local stand level vegetation structure and composition factors) than the surrounding landscape. Summerville and Crist (2001) pointed out that butterfly richness and abundance can differ among patches of various sizes and degrees of isolation.

Since no single taxon can adequately represent patterns for all other taxa (Pearson, 1996), incorporating both birds and butterflies into the metric would be an appropriate measure of overall diversity. However, using both birds and butterflies as a proxy for biodiversity makes the models complicated and confusing for two reasons. Firstly, the butterfly population is correlated not to stand age but to stand quality (Barlow, Overal, et al., 2007) and the latter is not a parameter in our models. Secondly, birds are claimed to be associated with mature forests (Hill, et al., 2001; Seaton, Minot, & Holland, 2010), while butterflies are more popular in young forests (Spitzer, et al., 1993); employing both taxa would create conflicting constraints in the models, which could make the models (i.e. finding optimal rotation ages with biodiversity constraints) infeasible (no solution) in several cases.

This study therefore uses only the number of birds as a proxy for biodiversity. Evidences show that bird richness and abundance are similar among forest types of the same region. Transferring bird data from one forest type to another (i.e. from data of natural forests to that of planted forests), therefore, is acceptable. In this study, ages of forest stands and forest age structure are taken into account when predicting the population size of birds.

3.2.3 The calculation of population size

There are several ways of identifying the population size of a species that have been proposed by ecologists and applied in integrated ecology and economic models. Firstly, a life-history simulator called PATCH, developed by Schumaker (1999), can be used to identify the population of a species over time in a particular landscape. This model was used by Calkin et al. (2002) to trace a flying squirrel population under different forest management for timber production over a 100-year planning horizon.

PATCH is a spatial model that tracks individuals as they are born, move, reproduce, and die under changing landscape quality and patterns. Therefore, PATCH is particularly suitable to identify species population under different forest management schemes. However, PATCH requires a lot of data, including habitat maps typically from a geographic information system (GIS) and data specifying habitat use (territory size and habitat affinity); vital rates (survival and reproduction); and the movement behaviour of the concerned species. There does not seem to be any checklist of vertebrate species in exotic planted forests in Vietnam. Thus, the type of data required for PATCH, which is more detailed than a checklist, is not available for this study area.

Similar to the PATCH model, Hurme et al. (2005) developed a spatial model to predict the flying squirrel population with existing knowledge about its habitat preference. This model was applied by Hurme, Kurttila, Monkkonen, Heinonen and Pukkala (2007) to analyse the maintenance of the squirrel habitat under timber harvest. This model, however, is site-specific. This means that to use the model for a particular area outside northeast Finland, a field survey for this area is needed to get the data to apply the model.

The third model, developed by Jetz, Carbone, Fulford and Brown (2004), has a simpler formula, compared to the two models mentioned above, to calculate the population size of a species in a particular landscape. This formula was used by Bateman et al. (2009) to calculate the population size of IUCN red-list species in Indonesia. Input into the formula included home range size, the effect of neighbourhood or resource supply used by other individuals, and the species-specific rate of supply of usable resources available in the home range area. According to Mac Nally, Fleishman, Bulluck and Betrus (2004), birds have home range sizes ranging from 4 to 40 ha. Other inputs into this formula can be adapted from Jetz et al. (2004). However, this formula cannot identify the population size of a species under different habitat quality (namely clear-cut, young, and mature forest stands), which is a main focus of this study.

3.2.4 The minimum viable population (MVP)

Vardas and Xepapadeas (2010) suggested that the SMS can be defined in terms of a MVP. Shaffer (1981, p. 132) defined that "A minimum viable population for any given species in any given habitat is the smallest isolated population having a 99% chance of remaining extant for 1,000 years despite the foreseeable effects of demographic, environmental, and genetic stochasticity, and natural catastrophes". He suggested that the critical level for survival probabilities might be set at any level, and the planning horizon can be lengthened to 10,000 or shortened to 100 years.

There are five possible approaches to determine the MVP sizes and their habitat requirements (Shaffer, 1981). Firstly, the experimental approach is to create isolated population sizes and monitor their persistence, but this approach is costly and time consuming. The second approach is biographic patterns that are the examination of the distributional patterns of species that occupy insular or patchy habitats when the length of their isolation is known. The third approach, genetic considerations, refers to the minimum population recommendations based on genetic and evolution arguments. The fourth approach is the use of theoretical models to determine MVPs. The final approach uses simulation models, which are more realistic and not subject to the various constraints of theoretical models. Due to budget and time constraints and also economic expertise, the last two approaches appear the most feasible and will be discussed in more detail below.

With regard to theoretical models, Koenig (1988) proposed a formula to calculate an effective population size for a given area. The inputs into the formula include population density, dispersal distance (distance travel from birth to breeding) and other control constants for overlapping generations, unequal progeny production, and non-normality of dispersal distance. This formula can be applied to find the MVP for birds if there is available data about overlapping generations, unequal progeny production, and non-normality of dispersal distance. However, this approach is criticised as embodying unrealistic assumptions or leading to currently unresolved mathematical problems.

Concerning simulation models, Reed, O'Grady, Brook, Ballou and Frankham (2003) suggested that wild populations of concerned species need to be maintained at approximately 7000 adult vertebrates in order to ensure long-term persistence. Traill, Bradshaw and Brook (2007) used a meta-analysis of 30 years of published estimates for 212 species and found that an average of 4169 individuals is considered as a MVP. They concluded that a viable population is context-specific. In many cases, there is insufficient data to do a species-specific population viability analysis (Shaffer, Watchman, Snape, & Latchis, 2002). Bulte and van Kooten (2001) and Franklin (1980) recommended that the MVP in the short or medium term is about 50−100 individuals, and approximately 500−5000 individuals in the long term.

There is still much debate about MVPs. All the approaches to identify the MVP discussed above are outside the scope of this research because they are written by non-economists and there is no data available. In this study, the MVP of birds for planted forests will be applied using a rule of thumb that there is an average of 50 individuals per year over a 50 year planning horizon (Bulte & van Kooten, 2001; Franklin, 1980). The MPV of 50 individuals will be used for a hectare of forest, rather than for the total forest area. This is because the chosen number was closest to the number of birds per ha in forests identified by Seaton et al. (2010) and Spitzer et al. (1993). The MVP will be varied in a sensitivity analysis to determine the trade-off between NPV and viable population. The difference between the NPV with and without the MVP is the cost to sustain a MVP of birds.

3.3 THE OPTIMIZATION MODELS

3.3.1 The timber optimization model

Assuming a forest consists of n stands with n equal to 1 for the stand level model, and greater than 1 for the forest level model. To analyse spatial arrangements among forest stands, it is assumed that forest stands are arranged into strips, i.e. stands are connected if they are next to each other. For example, stand 1 is adjacent to stand 2, and stand 3 adjacent to stand 2 and stand 4. Spatial interactions among forest stands are captured by economies of planting scale as follows. If adjacent stands are harvested at the same time, they form a larger planting area in the following year. A larger planting area ends up with a lower unit planting cost; and this is captured by equation (10).

The objective of the model is to maximize the net present value from harvesting timber. The planning horizon as well as the maximum length of the rotation interval for the simulations is 50 years, since, in Vietnam, both household forest owners and forest enterprises can use their forest lands for 50 years at most (Vietnamese Government, 1999).

Let $v(.)$: the discounted sum of timber value;

a_s: the area of stand s in hectares;

x_{st}: age of stand s in period t.

The model objective is to maximize the discounted revenue from timber:

$$(1) \qquad v(a_1,..,a_n; x_{10},..,x_{n0}) = \max \sum_{t=0}^{50} (1+r)^{-t} V_t$$

Subject to:

(2)	$d_{st} = 0$ or 1, $s = 1,..,n$,	*binary decision variables*
(3)	$x_{s,t+1} = (x_{st} + 1).(1 - d_{st})$, $s = 1,..,n$,	*age of stand s at period t+1*
(4)	$x_{st} \geq 0$, $s = 1,..,n$,	*nonnegative age constraint*

Where:

(5) r discount rate

(6) $V_t = \sum_{s=1}^{n} \left(q(x_{st}).\, a_s .\, d_{st}.P(x_{st}) \right) - G(h_t)$ timber value at the period t

(7) $q(x_{st})$ timber volume per ha of stand s in period t

(8) d_{st} the binary decision variable,

$d_{st} = 1$: stand s is clear-cut in period t

$d_{st} = 0$: stand s is kept in period t.

(9) P price of timber per unit volume

(10) $G(h_t)$ planting cost of timber at period t, which varies with planting size[10], $G(h_t) = \beta h_t^{\lambda}$, β and λ are estimated from the survey data. This function of planting cost captures spatial interactions among forest stands.

(11) h_t $= \sum_{s=1}^{n} d_{st}.a_s$: planting size in hectare in period t

3.3.2 The carbon optimization model

The carbon optimization model is an extended version of the timber optimization model described in the previous section. In this model, the value of carbon sequestration is included in the objective function as follows.

Let the $v(.)$ be the discounted sum of timber value (V_t) and carbon sequestration value (A_t). The model objective is to maximize the discounted revenue from timber and carbon over a 50-year planning horizon,

$$(12) \qquad v(a_1,..,a_n; x_{10},..,x_{n0}) = \max \sum_{t=0}^{50} (1+r)^{-t} (V_t + A_t)$$

and subject to (2), (3), and (4).

[10] There are no economies of planting scale in the Faustmann model.

Where:

(13) $A_t = (\sum_{s=1}^{n} Q_c(x_{st}).\ a_s\ .\ d_{st}).\ P_c$: value of carbon sequestered at period t

(14) Q_c amount of carbon sequestered, metric tonne per ha

(15) P_c carbon price per metric tonne

3.3.3 The biodiversity optimization model

The biodiversity optimization model is an extended version of the carbon optimization model by adding a constraint on the number of birds. Let MVP be a minimum viable population for birds per ha per year, the objective of the biodiversity model is (12), and subject to (2), (3), (4), and

(16) $\overline{S_{Bt}} >= MVP$ *minimum viable population for birds per ha per year*

Where:

(17) $\overline{S_{Bt}} = \frac{\sum_{t=1}^{50} S_{Bt}}{50}$ the average number of birds per ha over a 50-year period

(18) $S_{Bt} = \frac{\sum_{s=1}^{n} f(x_{st}, a_{st})}{\sum_{s=1}^{n} a_{st}}$ the number of birds per ha at period t.

Equation (18) implies that the number of birds depends on stand age itself and on the age structure of the whole forest. The bird abundance function, $f(x_{st}, a_{st})$, is estimated in section 3.5.3.

With regard to the biodiversity constraint, equation (16), using the average number of birds per ha over a 50-year period ($\overline{S_{Bt}}$) is problematic. Since requiring the average number (over 50 years) to be greater than the MVP means that in some years, the number of birds may be below the MVP. In those cases, when the population goes below the MVP, it may never recover. Thus, preferably the number of birds per ha per year (S_{Bt}) should be used. However, using that as a constraint will affect the performance of the biodiversity model as follows.

Using an MVP of 50 birds as a constraint implies that the number of birds (S_{Bt}) in the optimal solution should be greater than 50 in every year. This constraint however, can lead to infeasible solutions. The following example (Table 3.3) shows why this is so.

In this example, a forest consists of 5 stands (S1 to S5) with one hectare each in size. Stand ages at the start range from 1 to 5 years. The planning horizon is 50 years (t = 1,.., 50).

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}

Year in time horizon (t)	T=11						T=15					
	Total birds of the forest per ha per year (S_{Bt})	Ages of stands					Total birds of the forest per ha per year (S_{Bt})	Ages of stands				
		S1	S2	S3	S4	S5		S1	S2	S3	S4	S5
1	35	1	2	3	4	5	35	1	2	3	4	5
2	40	2	3	4	5	6	40	2	3	4	5	6
3	46	3	4	5	6	7	46	3	4	5	6	7
...*	...	...	...	...	...	...	...	...	...	...	...	...
10	55	10	11	0	1	2	125	10	11	12	13	14
11	43	11	0	1	2	3	144	11	12	13	14	15
12	30	0	1	2	3	4	127	12	13	14	15	0
13	35	1	2	3	4	5	108	13	14	15	0	1
...	...	...	...	...	...	...	...	...	...	...	...	...
30	71	6	7	8	9	10	85	14	15	0	1	2
31	81	7	8	9	10	11	60	15	0	1	2	3
32	74	8	9	10	11	0	30	0	1	2	3	4
33	65	9	10	11	0	1	35	1	2	3	4	5
...	...	...	...	...	...	...	...	...	...	...	...	...
46	55	10	11	0	1	2	85	14	15	0	1	2
47	43	11	0	1	2	3	60	15	0	1	2	3
48	30	0	1	2	3	4	30	0	1	2	3	4
49	35	1	2	3	4	5	35	1	2	3	4	5
50	40	2	3	4	5	6	40	2	3	4	5	6
The average number ($\overline{S_{Bt}}$)	**54**						**78**					

Note: * The continuing years in the planning horizon and their values.

As shown in Table 3.3, there are two possible optimal rotation ages (*T*) in the example, 11 and 15 years. Over a 50 planning horizon, there are some years that the number of birds (S_{Bt}) is less than 50 individuals, such as in year 2, 12 and 32 for *T=11*; and in year 2, 32 and 48 for *T=15*. In these years, the forest consists of clear-cut or young stands, and, as bird abundance is low at young stands, it is difficult to maintain biodiversity at 50 birds. This explains why using the indicator S_{Bt} will lead to an infeasible solution with a MPV of 50 birds for the biodiversity model.

As also shown in Table 3.3, however, the average number of birds over a 50-yearperiod ($\overline{S_{Bt}}$) is 54 and 78 individuals for an 11 and 15 years rotation, respectively. These average numbers show that the longer the rotation age, the higher the number of birds. This trend is in line with the literature that the number of birds increases with forest age. Using this indicator, the optimal rotation that has the highest positive NPV and meets the constraint in bird number could be possible. The study, therefore, uses the indicator $\overline{S_{Bt}}$ (the average number of birds per ha over a 50-year period) instead of S_{Bt} (the number of birds per ha per year).

3.3.4 The optimal subsidy model

When the private optimal rotations are shorter than the social optimal rotations, there is an opportunity for government intervention through, for example, a direct payment. While private forest owners take into account the value of timber production and carbon sequestration, social managers consider the same values as well as biodiversity maintenance in harvesting decisions. In particular, the objective of the private model is (12) and subject to (2), (3), and (4); and the objective of the social model is (12) and subject to (2), (3), (4), and (16).

This research assumes that private forest owners will receive a direct payment (*DP*) of VND/ha/year as long as their trees remain unharvested and, for simplicity, that this payment is constant and paid annually to the farmers from year 4 onwards. To find the optimal level of direct payment, following Koskela et al. (2007b), the optimal rotation age of the private owners will be equated to that of the social planners. The private optimization model with a direct payment (i.e. with timber and carbon values as well as a direct payment included) is solved, so that the privately optimal rotation age falls in line with the socially optimal rotation age. The payment level will be varied from 0 to 10,000,000 VND/ha/year with an interval of 10,000 VND/ha/year.

3.4 THE OPTIMIZATION METHOD AND DATA

3.4.1 The optimization method

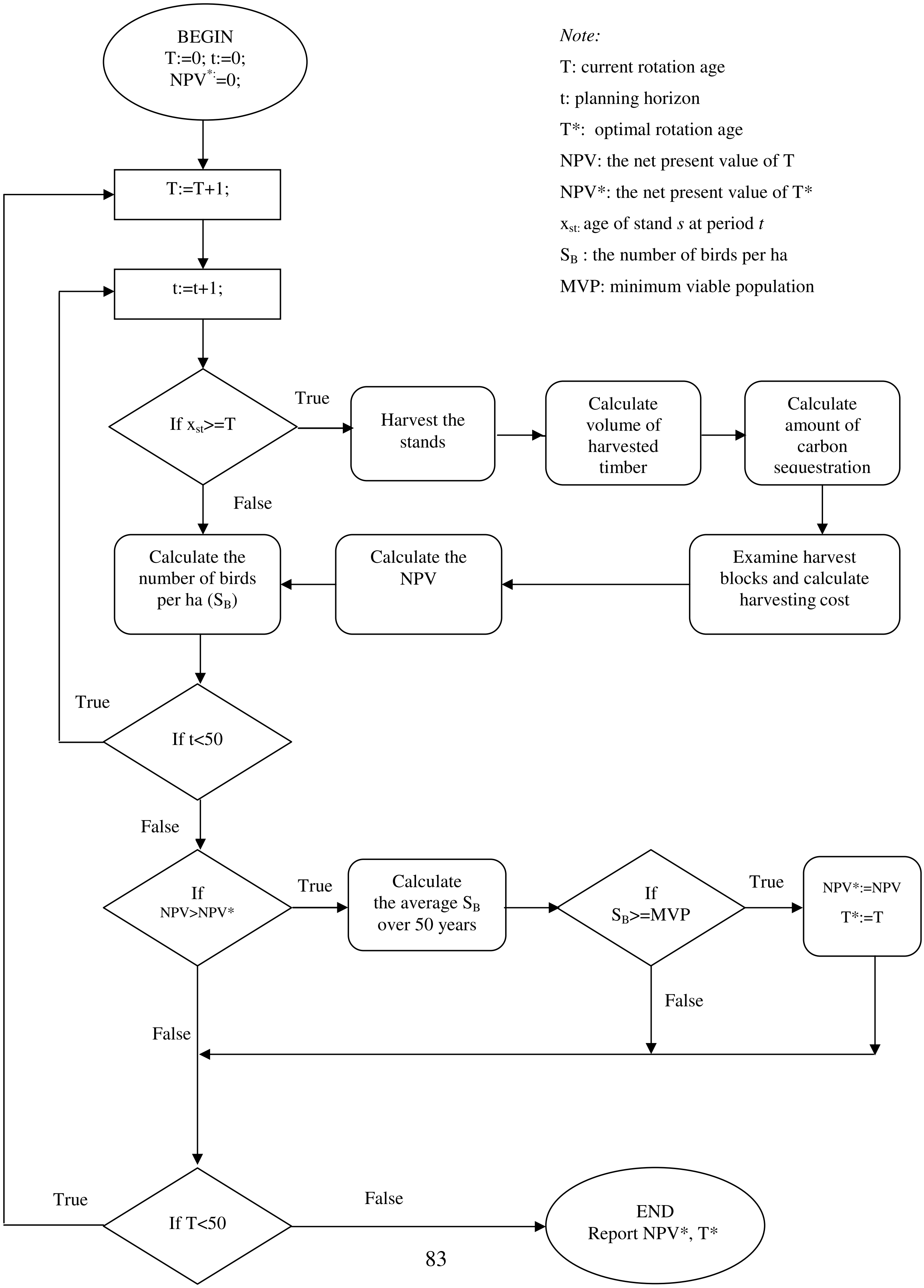
There are two popular methods for solving economic optimization models: analytical and numerical ones. It is preferable to derive a closed-form solution (using an analytical method) for an economic model if it exists. However, many economic models that attempt to capture the complexities of real-world economic behaviour, such as stochastic dynamic models (optimization problems involving uncertainty and changing input data), cannot be solved analytically using the standard mathematical techniques of algebra and calculus (Miranda & Fackler, 2002). The optimization models used in this study are dynamic and spatial, and hence, need to be solved by a numerical method. Although the numerical method is not preferred by some economists; it is better to derive economic insights from a realistic numerical model than to derive irrelevant results, however general, from an unrealistic model (Miranda & Fackler, 2002). Moreover, ad-hoc procedures with little mathematical foundation have been applied successfully to solve economic models (Judd, 1998).

Methods for solving numerical problems are divided into two basic types. The first methods are direct algorithms, which give exact answer in a predetermined finite number of steps. The second ones are interactive methods, which do not guarantee the true solution and require termination of the sequence at some finite point. The direct methods are always preferable unless absent or too time-consuming (Judd, 1998). The direct methods compute the objective and constraint functions at several points and pick the feasible point yielding the largest value. The advantages of these methods over analytical ones are that no derivative information is obtained, and no smoothness conditions on the objective and constraint functions are needed (Judd, 1998). Thus, the direct methods will be employed to solve the optimization models in this study.

In particular, the models described in section 3.3 will be solved by a direct search algorithm as follows: to find the optimal strategy, all scenarios with different rotation ages will be compared in terms of the objective variables and constraint, and the scenario that has the highest NPV will be chosen as the optimal strategy. This direct search algorithm is shown in Figure 3.1. The model will be coded in GAMS–General Algebraic Modelling System (APPENDIX C GAMS Coding).

To the best of my knowledge, there is no work that includes biodiversity value uncertainty at forest level or timber uncertainty with spatial interdependence at forest level. Considering growth uncertainty, stochastic interest rate and catastrophic risk might be interesting, however, it may make the model too complicated and hard to solve. In this study, sensitivity analyses will be performed by varying timber prices, the carbon price, carbon sequestration rates (i.e. using different carbon sequestration functions), and carbon payment schemes.

Figure 3.1 Graphical representation of the direct search algorithm



Note:

T: current rotation age

t: planning horizon

T*: optimal rotation age

NPV: the net present value of T

NPV*: the net present value of T*

x_{st}: age of stand *s* at period *t*

S_B : the number of birds per ha

MVP: minimum viable population

3.4.2 Model data

The optimization models described in section 3.3 will be applied to analyse optimal forest harvest strategies for case studies in Yen Bai province, Vietnam. To do this, both secondary and primary data of planted forests in Vietnam need to be obtained. Since no functions exist for timber growth, carbon uptake, and bird abundance in Vietnam planted forests that can be used in the study's optimization models, the study estimates them from available secondary data. Moreover, many inputs for the optimization models and policy analysis are not available in the literature. For those reasons, a survey is conducted to obtain demographic information and primary data on timber production and forest management strategies in Yen Bai, Vietnam.

The purpose of the survey is to obtain initial ages and stand arrangements of the private planted forests. The survey also targets planting costs and timber prices. These data are used as inputs for the optimization models. Moreover, the survey seeks information on foresters' attitude toward a payment system to lengthen rotation age and payments for carbon sequestration. Further, the survey aims to find out more about the biodiversity conservation attitude of the private forest owners in Yen Bai province, which will be useful for the analysis of the forest policy tools to enhance biodiversity in planted forest.

While the stand level models will be run using an average planting cost per ha, the forest level ones will be performed using a function for planting costs and will be applied to 10 forest cases. These 10 forest cases present a random selection (from 271 household forests in Yen Bai province) of forests with different stand numbers, sizes and stand ages (Table 4.8).

To analyse the optimal rotation age, the interest rate on the Government Bonds with 5 year maturity (the same time horizon with the actual tree cutting age), that is 8%, is chosen as the discount rate for household farmers (SIRIFIN, 2007; SSC, 2007; Xuan., 2007) since interest rates from commercial banks are less stable. Government Bonds can be used as an indicator for the discount rate since many individuals buy Government Bonds and stock for retirement (Moore et al., 2004). The discount rate commonly used in forestry is 5% (Daigneault et al., 2010), with a lower discount rate for developed countries, such as 3% for UK (Price & Willis, 2011) and 2.24% for US (Zhou & Buongiorno, 2011).

In sensitivity analyses, the discount rate was varied between 1 and 10%. This is because in some cases, social discount rates could be close to zero (Arrow et al., 1996). Moreover, household forest owners in Vietnam are not allowed to use their forestry lands for other land use purposes. This implies that households cannot invest their money (that is otherwise invested into planted forests) into other alternative projects or lend to the banks. Thus, forest households' discount rates are unlikely to go up very high (i.e., beyond 10% as commercial banks' lending rates).

In the analysis conducted in this research, the emphasis is on determining the optimal rotation age from a societal point of view, then compare with actual harvesting behaviour and then use payment incentives to bring actual behaviour in line with socially optimal behaviour. Actual harvesting behaviour of course reflects the time preference (discount rate) held by the individual forest owners.

Enterprises are likely to have a lower discount rate than households for usual reasons, such as they can easily, and are more willing to, borrow capital. Households with low income can have a higher discount rate than enterprises because of the high time preference for money (Naik, 1997). The government has regulated a special borrowing rate for forest enterprises, which is up to 4% lower than the normal borrowing rate for up to 2 years (Vietnamese Government, 2009).

Therefore, a 6% discount rate, which is 2% lower than households[11], will be used for enterprises.

3.5 GROWTH AND SEQUESTRATION FUNCTIONS AND BIRD POPULATION

3.5.1 Timber growth function

Timber growth functions of *Eucalyptus urophylla* and *Acacia mangium* for Site index II are estimated from data obtained from MARD (2003):

Eucalyptus urophylla:

$$(19) \qquad q(x_{st}) = -1.38x_{st}^2 + 40.33x_{st} - 94.07, \; R^2 = 0.99$$

Acacia mangium:

$$(20) \qquad q(x_{st}) = -0.3x_{st}^2 + 28.06x_{st} - 63.33, \; R^2 = 0.99$$

where x_{st} denotes timber age and $q(x_{st})$ represents timber volume at age x_{st}. Taking the first derivative of these timber growth functions shows that timber growth reaches its maximum at aged 15 and 47 years for *Eucalyptus urophylla* and *Acacia mangium*, respectively.

The timber growth functions in equations (19) and (20) will be used to calculate timber volumes for enterprises. According to MONRE (2005), household's timber productivity is approximately one third of the productivity provided in the yield

[11] A discount rate at 4% lower than the normal borrowing rate for up to 2 years is approximately equivalent to a discount rate at 2% lower for 5 years.

table (MARD, 2003). Thus, a timber growth equation equaling $q(x_{st})/3$ will be used for households.

3.5.2 Carbon sequestration function

To identify the amount of carbon uptake, carbon sequestration functions from Vo, Dang, Nguyen, Nguyen and Dang (2009) are used. Since Vo et al.'s functions are not suitable for application to planted forests beyond 7 years of age, their carbon sequestration functions are adjusted as follows. Firstly, using tree density data from Tables of Site Index (MARD, 2003) and tree density at planting from the survey[12], a relationship is calculated between stand age and tree density for households and enterprises. Secondly, the amount of carbon uptake is obtained by running the carbon sequestration functions from Vo et al. with respect to stand age and tree density for site index I[13] for *Eucalyptus urophylla* and site index II for *Acacia mangium*[14]. Finally, the amount of carbon uptake and the associated stand age are used to re-estimate the carbon sequestration functions for use in the optimization models. The final functions are as follows.

[12] From our survey, tree density of both species at planting is 2189 and 1660 trees/ha for households and enterprises, respectively.
[13] The carbon sequestration from Vo et al. is $LnQc=22.036 + 0.313lnX-1.584lnN$, where Qc is amount of carbon uptake (kg/ha), X is age of tree, and N is tree density (per ha).
[14] We used tree density at age 12/13 for *Eucalyptus urophylla/Acacia mangium* for the rest of rotation so that the amount of carbon sequestered not increase too high, say 30 thousand tonnes/ha.

For households of *Eucalyptus urophylla*:

$$(21) \quad Qc(x_{st}) = -0.071x_{st}^2 + 6.0155x_{st} + 11.567, R^2 = 0.9633$$

For enterprises of *Eucalyptus urophylla*:

$$(22) \quad Qc(x_{st}) = -0.1101x_{st}^2 + 9.3232x_{st} + 17.928, R^2 = 0.9633$$

For households of *Acacia mangium*:

$$(23) \quad Qc(x_{st}) = -0.0305x_{st}^2 + 4.9714x_{st} + 66.114, R^2 = 0.9921$$

For enterprises of *Acacia mangium*:

$$(24) \quad Qc(x_{st}) = -0.0271x_{st}^2 + 4.42x_{st} + 58.781, R^2 = 0.9921$$

where x_{st} denotes timber age and $Qc(x_{st})$ represents the carbon amount (tonne/ha) sequestered up to age x_{st}. Taking the first derivative of these carbon sequestration functions for households shows that the carbon amount reaches its maximum at aged 42 and 81 years for *Eucalyptus urophylla* and *Acacia mangium*, respectively.

As mentioned above, the carbon sequestration functions by Vo et al. (2009) are adjusted so that these functions fit the optimization models. A sensitivity analysis will be performed with other carbon sequestration functions for *Eucalyptus urophylla* for households by Vo et al. namely:

$$(25) \qquad Qc(x_{st}) = \frac{e^{22.036+0.313\ln(x_{st})-1.584\ln(N)}}{1000}$$

$$(26) \qquad Qc(x_{st}) = \frac{(e^{4.1343-4.6438/x_{st}})N}{1000}$$

where N denotes tree density (trees/ha). It is assumed that tree density is 2189 trees/ha (from the household survey data) in order to calculate the carbon amount for a hectare.

3.5.3 Bird abundance function

There is no available data to use the models mentioned in section 3.2.3 to predict the population size for birds (Hurme, et al., 2007; Jetz, et al., 2004; Schumaker, 1999). Therefore, total species abundance (i.e. the sum of all birds) is estimated as a function of forest age and is calculated from data derived from the literature. Since there is little difference in bird richness and abundance among forest types and between managed and unmanaged forests (discussed in section 3.2.2), the data for planted forests is adapted from natural forests or protected areas in Vietnam.

In particular, data about heights of trees for birds from Table 4, p. 56 (Hill, et al., 2001) are used to estimate bird abundance. The number of all birds appearing on the ground, from 0−1.5 m, 1.5−4m, and above the 4m canopy are added together (Table 3.4). Data about bird abundance at various heights among trees are used for ages of stands. That is the bird abundance near the ground is transferred to a one year stand; from 0−1.5 m to a three year stand; 1.5−4m to a ten year stand; and above the 4m canopy to a 20 year stand (Table 3.5).

Table 3.4 Total abundance of all birds according to vertical height above ground

Vertical height above ground (m)	Ground: 0	0–1.5	1.5–4	Canopy: > 4
Total abundance of all birds	34	21	122	351

Source: Adapted from Table 4, p. 56 (Hill, et al., 2001)

Table 3.5 Total abundance of birds at different stand ages (transferring from heights of trees)

Age of stands (year)	1	3	10	20
Total abundance of all birds	34	21	122	351

Source: Calculated from Table 4, p. 56 (Hill, et al., 2001) and the yield table for *Eucalyptus urophylla* (MARD, 2003).

It is important to note that the pattern of bird abundance at different forest heights in a natural forest is correlated with the interactions among layers of forest canopy themselves. In planted forests, trees with different heights are actually in separate areas (different stands), and thus, there is no interaction among layers of forest canopy. However, because there are no other data available relating to planted forests exclusively, natural forest data are adopted to estimate bird abundance in planted forest stands. The conversion of heights of trees into ages of stand is based on the yield table for *Eucalyptus urophylla* (MARD, 2003).

Using Table 3.5, the relationship between the number of birds and stand age is estimated as $S_{BT} = 22.215e^{0.1421x}$, $R^2 = 0.9179$, where S_{BT} is total bird abundance per ha and x is age of forest stand[15]. This functional form is chosen since it best fitted the data (highest score of R^2, Figure 3.2). This functional form corresponds to findings in the literature discussed above, for example, birds prefer mature forest, closed canopy, and complex structure. For the illustrative purpose, various functions, including the one chosen, are plotted for stand ages ranging from 0 to 20 years (Figure 3.3).

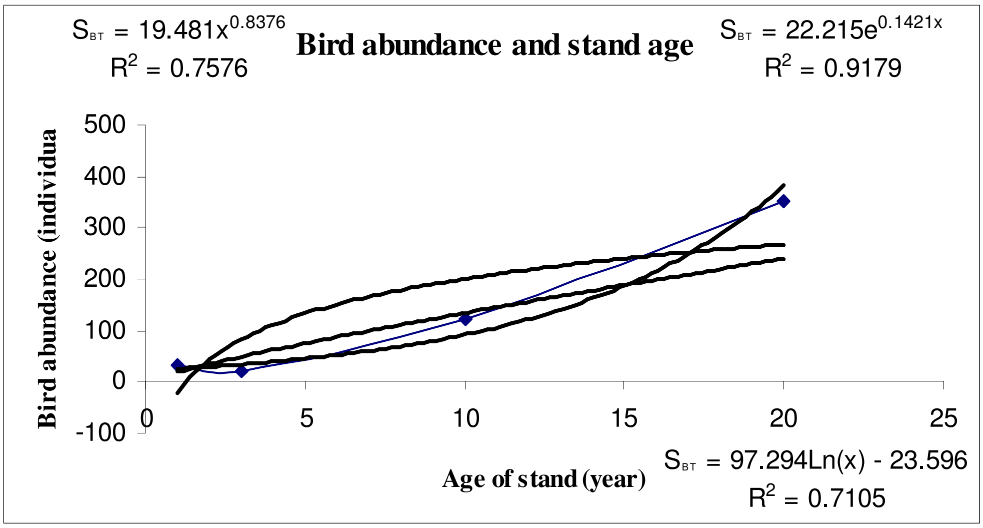


Figure 3.2 The bird abundance and age of stand

[15] In the study by Hill et al. (2001), there does not seem to be any information on the scale unit of bird abundance (for example, per ha or per km^2). Nevertheless, the results of the total bird abundance coming from the estimated function in this study ($S_{BT} = 22.215e^{0.1421x}$) are similar to those of the total bird abundance per ha in the study by Seaton, Minot, and Holland (2010). Therefore, the bird abundance function in this study is expressed per ha.

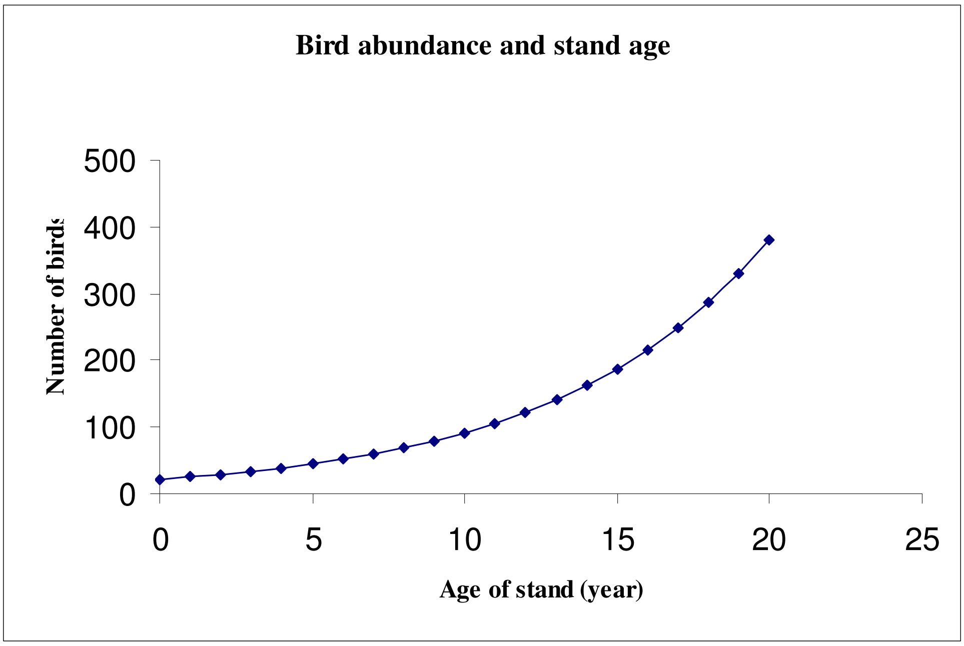


Figure 3.3 The function for bird abundance and age of stand:
$S_{BT}=22.215e^{0.1421x}$

3.6 THE SURVEY

3.6.1 Questionnaire development

Questionnaires were developed for forest households and enterprises based on the model specification and on a previous study on timber production in Yen Bai province (Nguyen et al., 2006). The quesionnaires contain five parts. Part I obtains information on age, gender, ethnicity, education, size of household, labour and financial status. Part II obtains questions on size of forestland and other land holdings, cutting practices, initial stage of forest, understorey plants, and biodiversity conservation attitudes. Part III obtains information on timber production costs, capital and subsidies from the government. Part IV concerns 2007 income levels from forest and other sources. Part V investigates the management strategy regarding rotation lengths, government subsidies, methods of payment for carbon sequestration, and carbon pooling (households' forestland are managed together for the provision of carbon sequestration services).

Preliminary field work was conducted to identify whether it is possible to obtain data for the variables specified in the questionnaires. The questionnaires were sent to EEPSEA advisors, experts at Vietnam Forestry University, researchers engaging in the CDM project in Hoa Binh (Vietnam) and people at Vietnam Ministry of Agricultural and Rural Development for comments and validation. Comments related to the wording (how would households understand the questions) of the questions, the sample size and volume, and the order in which the questions were asked.

The questionnaires were pretested using 10 researchers in the forestry sector in Vietnam and after revision tested further on 10 households and one forest enterprise in Yen Bai province. Respondents had no idea about the site index of their land and often grow several species in their forests. This was taken into account in the finalization of the questionnaires (APPENDIX B Questionnaires).

3.6.2 Survey implementation

The study sites include the Tran Yen, Van Yen, and Yen Binh districts. Two communes in each of the three districts were selected based on consultations with local government officials. These are Viet Cuong and Cuong Thinh in the Tran Yen district, Ngoi A and Yen Thai in the Van Yen district, and Vu Linh and Vinh Kien in the Yen Binh district. The sample population consists of households who grow *Eucalyptus urophylla* or *Acacia mangium* and own a productive forest of at least 0.5 hectares. Lists of households who own at least 0.5 ha of planted forests were obtained from the heads of communes. Households were selected randomly using Microsoft Excel 2003 (i.e. using the RAND function).

Surveys were implemented in September 2008. Survey methods were adopted using practices from the literature (Groves et al. 2009; Litwin 1995; Fink 2008) in order to minimize survey errors. Examples are how to put questions in an order so that the questions that follow are not biased by earlier questions; how to train interviewers in order to minimize interviewer bias; and guidelines for pilot testing. Enumerators include lecturers and students from Vietnam Forestry University, and staff from the Institute of Environment and Ecology in Xuan Mai, Hanoi. The enumerators that were used all had previous survey experience and for this survey did receive two days of training. During the interviews, the interviewers had to make sure that only they and the respondent attended the interview, that the question were asked following the exact order in the questionnaires; that no questions were skipped and that respondents were given plenty of time to answer the whole question in order to minimize face-to-face survey bias. If none of the adult(s) of the selected households were at home, a re-visit at night was required. The enumerators were requested to enter data into an Excel template file at the end of the day, and to keep data in safe place and confidential.

A total of 271 usable questionnaires out of 291 distributed were collected (Table 3.6). Data were cross-checked by enumerators, cleaning (i.e. checking min, max, missing data, and invalid data) and coding before being analysed.

Table 3.6 Location and sample size

Location	Sample size		
	Total household	*Eucalyptus urophylla*	*Acacia mangium*
Viet Cuong and Cuong Thinh communes, Tran Yen district	93	1	92
Ngoi A and Yen Thai communes, Van Yen district	88	6	101
Vu Linh and Vinh Kien communes, Yen Binh district	90	79	44
Total	**271**	**86**	**237**

Four state forest enterprises were interviewed, namely Viet Hung, Thac Ba, Van Yen, and Yen Binh. To get further data for the research, a private forest enterprise, a special management board, the Yen Bai Forestry Department, and other forestry departments at district-level and commune-level were also interviewed.

3.6.3 Data analysis

This section presents an analysis of the data obtained from the survey. The data are processed in two phases. Firstly, the semi-open ended interviews are transcribed and coded in MSExcel. Secondly, the collected data are analysed using the descriptive statistics and correlation methods in SAS version 9.1. Data are categorized according to the type of information obtained. This includes demographic data, planting costs and timber price, management for carbon sequestration, and biodiversity conservation attitudes. The demographic information is used, together with other data, to analyse payments for carbon sequestration and policy tools for enhancing biodiversity.

Data on planting costs are used to estimate planting costs functions (as a function of harvest size) for each of the dominant tree species. The sample size of households is 86 for *Eucalyptus urophylla*, and 237 for *Acacia mangium*. Since planting costs of enterprises were given as a cost per ha, they will be averaged from that data. Timber prices, for each dominant tree and each group of ownership, will be averaged. Finally, the calculated planting costs and timber prices will be used as the inputs for the optimal management models.

The management strategies data for carbon sequestration obtained from household respondents (n=271) are also transcribed and coded in MSExcel. The data include both qualitative and quantitative information, such as the management strategy regarding rotation lengths, payments from government, methods of payment for carbon sequestration, and carbon pooling. The data are processed using descriptive methods and a cross tabs analysis in MSExcel.

Conservation attitudes play an important role in conserving biodiversity. If local people do not support the establishment of protected areas, then these areas cannot be maintained (IUCN, 1993). Conservation attitudes are significantly influenced by education of local people (Tomicevic, Shannon, & Milovanovic, 2010). The data acquired from the household survey are analyzed to understand biodiversity provision in planted forests and the conservation attitudes of the forest owners.

The conservation attitude variables include understorey awareness (whether there are any understorey plants in planted forests), understorey value (whether understorey plants possess any value), biodiversity support (whether the respondents agree/not agree to enhance biodiversity in planted forests if they could be supported financially), and reasons for support/not support maintaining biodiversity. The general variables refer to age of the respondent, ethnicity, gender, education, household size, poverty, and forest area. Following Tomicevic et al. (2010), the analysis of the correlation between the variables is conducted using Spearman's nonparametric methods of rank correlation since it is applicable for qualitative data.

In summary, attitudes towards biodiversity obtained from this survey are analysed in combination with the review of policy tools and socio-economic context in Vietnam in order to recommend an effective policy tool for planted forests in Vietnam. The optimal level of direct payments for biodiversity conservation obtained via the model described in section 3.3 is also used in the recommendation of policy tool.

CHAPTER FOUR. RESULTS AND DISCUSSION

4.1 INTRODUCTION

The objectives of the research conducted are to determine in detail the optimal rotation ages for planted forests, in Yen Bai province, when carbon sequestration and biodiversity conservation benefits are included in the overall decision making to maximise society's wellbeing. In this chapter, the results of the analyses are presented as well as the results of the survey conducted to obtain data on the growing of plantation forests by individuals and enterprises and to determine actual harvesting strategies.

This chapter is organised as follows; the next chapter presents the survey results including an analysis of the data. Sections 4.3 and 4.4 present the optimal rotation ages and sensitivity analyses for the models under various price, costs and productivity assumptions. The final section analyses various policy tools to encourage alignment of private and social optima and discusses optimal levels of direct payments needed to create the appropriate economic incentives to achieve this.

4.2 THE SURVEY

This section starts with the descriptive data obtained from the interviews with forest owners in Yen Bai province in 2008.

4.2.1 Descriptive data

The first part of the questionaires used in the survey obtained demographic data of the forest owners. The second part obtained information regarding the forest owners' production situations. These data are summarized and presented in Table 4.1 and Table 4.2.

Table 4.1 General information on the household forest owners

Variable	Unit	Mean (Standard deviation)
Age	years	46 (10.45)
Sex	female=1	0.15 (0.36)
Ethnicity	minority groups =1	0.47 (0.5)
Education	years	8/12 (2.96)
Household size	people	5 (1.46)
Household labour	people	3 (1.21)
Financial status	well-off =1, poor =2, and average =3	2.67 (0.7)

As shown in Table 4.1, the average age of respondents is approximately 46 years, average level of education is 7.6 per scale of 12 (12 being final year of high school), and almost all of them (85%) are male. Nearly half (47%) of forest households belong to minority groups, namely Tay, Cao Lan, Dao, and Nung; the rest are from the Kinh group. The average household size is 4.84 and over half of the family members are labourers. Eighty percent of the households can be classed as middle-class income, 6.3% as poor, and the rest as well-off.

Table 4.2 Production information on the household forest owners

Variable	Unit	Mean (Standard deviation)
Productive planted forest area	ha	3.95 (4.62)
Agriculture land	ha	0.19 (0.13)
Other land	ha	1.18 (7.18)
Distance from planted forests to main roads	km	1.11 (1.27)
Number of stands in planted forest	stands	2.54 (1.04)
Harvest age	years	5.17 (1.47)
Agriculture revenue per ha of agriculture land	million VND/ha	134 (174.31)
Planted forest revenue per ha of forest land	million VND/ha	9.9 (8.15)

Table 4.2 shows that the average planted forest area is 3.95 ha, 20 times and 3 times higher than agriculture and other land holdings in the region, respectively. The average distance from planted forests to main roads is 1.11 km. A planted forest normally consists of 2.54 stands. Actual harvesting age of household planted forests is 5.17 years. Revenue per hectare from agricultural activities is 14 times higher than for forestry. This result is consistent with forest farmers' desire, noted during household interviews, to shift their land to agricultural use.

The data also show that almost all (267/271) households own their forest land. Ninety one percent of the owners applies a clearcut practice to harvest their forests. Among the 271 respondents, 32 grow *Eucalyptus urophylla* only, 78 grow *Acacia mangium* only, and 171 grow mixed species but in single stands.

With regard to state forest enterprises, their planted forest areas are several thousand hectares. For example, the planted forest area is 1,400 ha for Yen Binh and 2,000 ha for Viet Hung enterprises, respectively. The size of forest stands ranges from 2.5 to 3 ha. The number of staff is between 100 and 200 people. These enteprises grow both *Eucalyptus urophylla* and *Acacia mangium*. The average harvesting age of enterprise planted forests is 7 years. The planted forest revenue of total forest land is from 0.3 to 1.5 million VND per year.

4.2.2 Planting cost and timber price

The information obtained from the production costs and consumption information parts of the questionnaires is used to calculate planting cost functions and timber prices for the two dominant tree species. To estimate the cost functions for the two species, planting costs obtained from the survey are adjusted by inflation rates (Table 4.3) to express them in 2007 values. Average planting costs and timber prices are shown in Table 4.4 and Table 4.5.

Table 4.3 Inflation rate in Vietnam

Year	2000	2001	2002	2003	2004	2005	2006	2007
Inflation rate (%)	-1.6	-0.4	4.0	4.3	7.8	8.4	6.6	8.2*

Source: * World Bank (2008) and ADB (2007)

Table 4.4 Planting costs

Species	Household's planting cost (million VND/ha)	Enterprise's planting cost (million VND/ha)
Eucalyptus urophylla	6.85	17.02
Acacia mangium	6.77	14.09

As shown in Table 4.4, for households, the planting cost of *Eucalyptus urophylla* per ha is 6.85 million VND per ha, 0.07 million VND higher than that of *Acacia mangium*. The planting cost are expressed in 2007 Vietnam Dong. For forest enterprises, the average planting costs (including planting cost, tending cost up to year 3, and other costs) are estimated from the enterprises' data. The costs come to 17.02 million VND per ha for *Eucalyptus urophylla* and 14.09 for *Acacia mangium*. These costs are higher than those of households since enterprises use more fertilizers (five times higher) and bear other associated costs such as management, and design.

Table 4.5 Timber price and revenue in 2007

Species	Selling place	Average timber revenue per ha (million VND)	Average timber price per m^3 (million VND)
Eucalyptus urophylla	Stumpage price	19.38	**0.37**
	Landing 1	22.06	0.44
Acacia mangium	Stumpage price	12.89	**0.33**
	Landing 1	10.39	0.35

Table 4.5 presents timber revenues and timber prices for two selling places: at the seller's property (stumpage price) and at the local market (landing 1). Timber revenue per ha per rotation (under stumpage price) for *Eucalyptus urophylla* is nearly 7 million VND higher than that for *Acacia mangium.* The majority of the forest owners sell stumpage trees. Thus, the average stumpage timber price of 0.37 and of 0.33 million VND per m^3 for *Eucalyptus urophylla* and *Acacia mangium* are used to calculate Faustmann rotations for both households and enterprises.

The cost functions, which take into account economies of scale in planting, for *Eucalyptus urophylla* and *Acacia mangium* are presented in Figure 4.1 and Figure 4.2, respectively. These functions are used in the optimization models. The planting cost function for *Eucalyptus urophylla* has been derived from the household survey data and is:

(27) $$G(h) = 5.16h^{0.98}, R^2 = 0.66$$

where *h* denotes planted area (ha) and *G(h)* represents planting cost (million VND per ha). The level of economies of scale (λ) shows a small decrease cost in planting as the scale in tree planting increases.

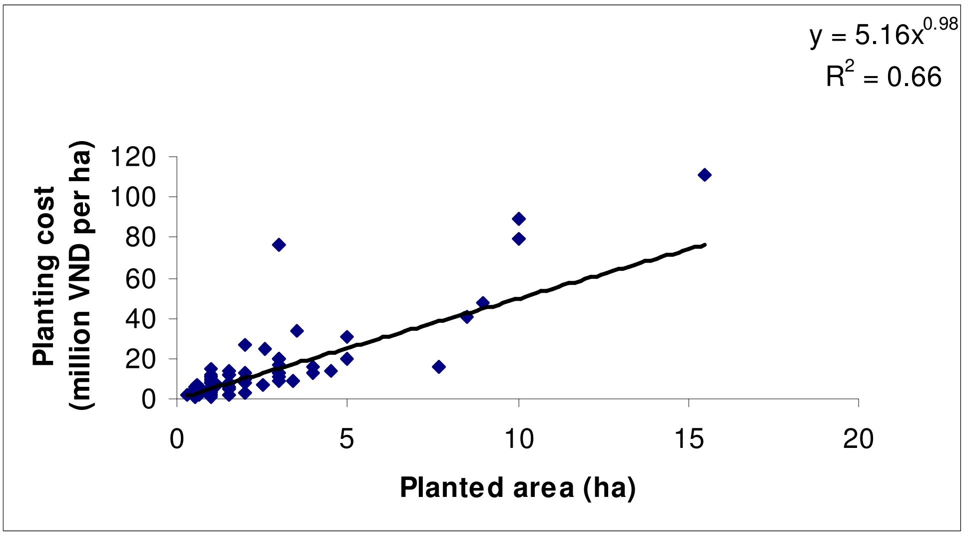


Figure 4.1 Planting costs for *Eucalyptus urophylla*

Similarly, the planting cost function for *Acacia mangium* is as follows (Figure 4.2).

(28) $$G(h) = 4.56h^{1.07}, R^2 = 0.66$$

In the case of *Acacia mangium*, the level of economies of scale (λ) equals *1.07***.** This means that planting costs for *Acacia mangium* show an increasing cost to scale of planting.

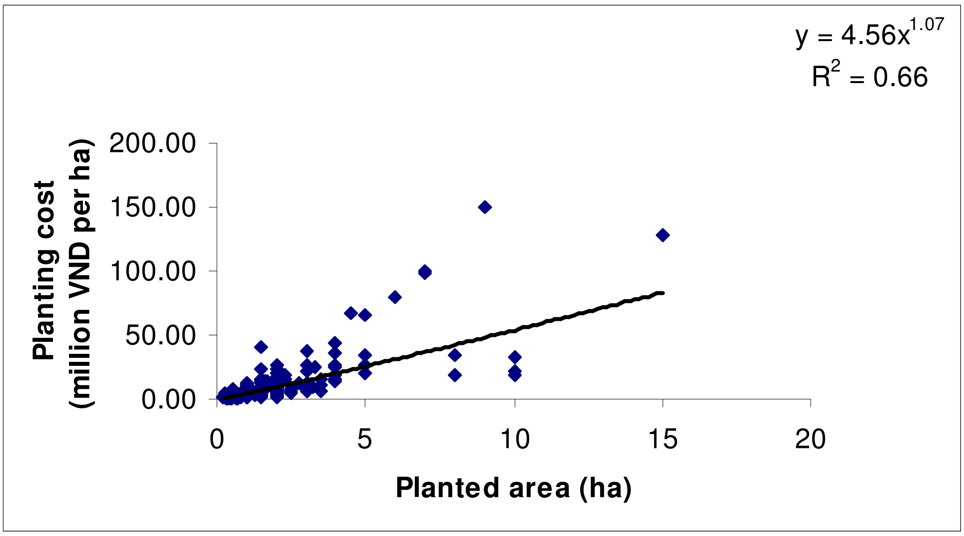


Figure 4.2 Planting costs for *Acacia mangium*

As the results show, there are nearly no economies of scale in planting costs for both tree species. It might be because more than 70% of Yen Bai province is mountainous and highland area, with large distances among forest stands of the same owners, and a low level of machine application. Further, it is hard to measure economies of scale since households employ different techniques, amounts of capital, labour, and fertilizer in their forests. This means planting costs depend on households' practices. However, the function of economies of scale is still used to calculate a forest level rotation for *Eucalyptus urophylla*. Sensitivity of the rotation age to the value of λ is presented in the section on sensitivity analysis.

A function for economies of planting scale is not estimated for forest enterprises, because there is no data. The Vietnamese Government pre-determines planting costs per hectare for enterprises (Vietnamese Government, 2005b). Based on the Government's figures, forest enterprises develop beforehand tables of estimated planting costs for each species per hectare.

4.2.3 Forest management for timber production and carbon sequestration

In the survey, forest owners were questioned about forestry management practices, the role of government (subsidies) and their attitudes to policies encouraging carbon sequestration. In this section, the findings of the responses are presented and discussed.

The survey shows that 4.8% of households receive a subsidy from the Government to grow their trees. The subsidy is given in the form of lower seedling prices. According to the Faustmann model (1849), this type of subsidy will help to reduce planting costs, and hence, induce a shorter rotation interval. About 73.4% of households use their own capital to invest in their forests, so lower interest rates from bank loans may not be relevant to the majority of forest households. It is likely that risk aversion prevents households from borrowing money from banks.

Harvesting decisions are 48.3% based on timber age, 28.4% on family financial status, 12.2% on timber price and the rest for other reasons. Family financial status is the second main reason to cut trees sooner than suggested by the Faustmann model. Decisions regarding tree species depend largely on the profitability of the species (48%), on family financial status (25.5%), on decisions of adjacent households (12.2%), and the rest for other reasons.

Ninety three point four percent of forest owners would delay their harvest if they were financially supported by the government with an average amount of 5.5 million VND per ha per year. The reasons for choosing that level of compensation can be explained by living costs and debt (46.2%), production costs or other incomes (20.6%), price and volume uncertainties (10.3%), and other reasons (22.9%). Again, family financial status plays an important role in the decision of household forest owners regarding tree cutting.

In the survey, forest owners were also asked about their willingness to participate in a pooling arrangement. Under such an arrangement, the land of several households is bundled to form a larger project size. The households must act together regarding types of dominant tree species, harvest decisions, and benefit sharing mechanisms. Besides the income from selling the timber, the participants will be given some payments for carbon sequestration. Pooling arrangement will help to reduce transactions costs significantly and can take advantage of economies of scale (Gong, Bull, & Baylis, 2010; Grieg-Gran, Porras, & Wunder, 2005).

The results show that nearly 89% of households would agree to such a carbon pooling arrangement. The reasons given are that they believe they would benefit from technical support, forest protection, and economies of scale (42.9%); have more capital to invest in their forest (5%); have environmental benefits (13.4%); and other reasons (38.7%). Regarding carbon pooling paper work, 47.3% of respondents said that a contract between households and the investor would be necessary, 21.8% needed to see more information on the rules of the project, and 31% had no ideas about procedures to establish the project. When asked if they could foresee any obstacles to a carbon pooling agreement, 22.9% of the forest owners said they saw no obstacles, 15.9% worried about catastrophic risks and price uncertainty, 8.1% were afraid of the investors going bankrupt, 4.8 % of them answered that poor households may cut trees earlier, 5.9 % gave other obstacles, and 42.4% had no ideas (whether obstacles would occur).

While illegal logging still remains a major challenge to many countries in Asia (Lawson & MacFaul, 2010) it is an issue for natural forests, not for planted forests with short rotation ages which are the focus of this research. A survey of households in a province with high rates of illegal logging in Vietnam shows that only 2% of the households who committed illegal logging got timber revenues from these logs, and the rest of the households did that for medicine, religious, and house building purposes (McElwee, 2004). As planted forests are not rich sources of non-timber forest products and their timber is not suitable for religious purposes, illegal logging is not a big issue in planted forests. My survey in Yen Bai province indicates that households do not have to pay for protection costs of their forests. The reasons are that timber from planted forests is of low value and heavy (hence transportation cost is a large proportion of total revenue). Therefore, people who commit illegal logging in planted forests normally live within the region. In Yen Bai province, as in many rural parts of Vietnam, people in the region know each other well, and the majority of them have planted forests. Hence, they do not steal trees from their neighbours' planted forests. Illegal logging may be a problem with forest enterprises, however, my analyses and policy implications focus on households, not on forest enterprises (since there is no forest-level model for enterprises because their planting costs are predetermined by the Government). Therefore, illegal logging is not a potential problem to my study. To say it differently, I assumed there is no illegal logging in household planted forests.

4.2.4 Payment for carbon sequestration

To encourage forest owners to adopt the optimal rotation length when carbon sequestration has a value, payment for carbon sequestration needs to consider the preferences of the local forest owners. The survey obtained the opinions of the household forest owners with regard to carbon payment schemes. The findings of the survey with regard to two schemes, annual and upfront carbon payments, are presented next.

The two proposed carbon payment schemes, annual versus upfront payments, are weighted by the respondents, 51.7% and 48.3% respectively. For the annual payment scheme, forest farmers would be given annual carbon service payments from forest canopy closure or from year 4 onwards until forest harvesting. For the upfront payment scheme, forest farmers would be paid for carbon service in full at forest establishment and they would have to sign a pledge to keep their forests until they reach a certain age. The survey results show that forest owners would want an average amount of 21.4 million VND per ha per rotation from carbon benefit for them to keep their trees till age 11 years on average.

A cross tabs analysis, to understand the characteristics of forest households in the annual and upfront payment groups, shows that households who chose the annual payment belong to a low income group, are more dependent on income from planted forests, more concerned about money for their living, and less interested in a carbon pooling project. The characteristics are analysed in more details as follows.

With regard to income levels, the data show that households in the annual payment group earn less income in total compared to those of the upfront payment group. Households that chose the annual payment also use more household labour and provide more outside labour (work for other individuals or institutions) compared to households preferring the upfront payment. A majority of the respondents who belong to minority communities, which are recognized as poorer in comparison to the Kinh group, also chose annual payment.

Further, the annual payment group gets more of their income from productive forests and less income from other sources; even though they provide more outside labour. This is because the outside job of the annual payment group are low skilled, and thus, are paid less compared to the upfront group. This result follows from the fact that the level of education in the annual payment group, on average, is lower than that in the upfront payment group (7.34 and 7.95 over the scale of 12, respectively). The data imply that the annual payment households are more dependent on planted forests, and that this is likely the major reason why they selected annual payments from planted forests to secure a constant source of income for their living. The reasons given for harvesting decisions made by households also clearly support this hypothesis. Thirty one percent of households who preferred payment annually stated that they cut their trees because of financial reasons, i.e. lack of money for their everyday basic needs, compared to 24% in the other group.

The next characteristic of forest households who chose annual payment is that they seem to be more worried about money for living than the other group. In particular, the majority of the respondents would agree to delay harvest if they were subsidized by the Government, especially those in the annual payment group. When being asked why they were willing to delay harvesting if subsidized by the Government, 47% of the annual group related their answers to financial ability, living costs and debts, compared to 42% of the upfront payment group. Again, in the expression of households' opinions about the carbon pooling project, the respondents who preferred the annual payment were much more concerned about capital and money (10%) than those who chose the upfront payment (4.6%).

Households in the upfront payment group seem to be more optimistic than those in the other group. This is also shown by more of the upfront payment people being willing to engage in the carbon pooling project compared to the other group. Further, when the interviewers asked if the respondents anticipated any difficulties in the implementation of the carbon pooling project, 30% of the respondents in the upfront payment group believed there would be no obstacles while only 18% of those in the other group had that belief.

In conclusion, households who preferred the annual payment seem to be poorer, more vulnerable (that is more dependent on planted forest income), and less sure about the success of the carbon pooling project. It is likely that this group of households did not choose the upfront payment with a commitment because they are afraid the commitment might bring inflexibility in times when they need to sell their trees for everyday basic needs or living costs.

4.2.5 Biodiversity conservation attitudes

In this section, biodiversity conservation attitudes of the forest owners obtained from the survey are examined. The section is divided into two parts. The first part describes the descriptive data regarding understorey value, understorey awareness, and biodiversity support from the forest owners' opinions. The second part analyses the relationship (i.e. correlations) between the characteristics of the forest owners and their attitudes towards biodiversity conservation.

With regard to the descriptive data, the first question in the survey regarding biodiversity was whether there are wildings and understorey cultivated crops in the respondents' planted forests. Sixty one percent of the forest owners said wild understorey plants were found, 19% said there were none, and the remainder reported that they cultivated crops under the shade of the forests. A follow-up question asked whether those plant species had market value, soil and watershed protection value, scenic value, and genetic diversity, or possessed no value. Among the respondents, 41% thought that understorey were marketable, 15% chose the option that understorey plants provided soil and watershed protection, 17% said that they contributed to genetic diversity, and the remaining 27% believed they possessed no value. Even though scenic value was presented as an option, it was not chosen by the respondents.

Concerning the forest owners' willingness to enhance biodiversity, interestingly a majority of the respondents (63%) were in favour of improving biodiversity in their forests if they would be supported financially. The dominant expectation of the respondents for agreeing to enhance biodiversity was that they would receive money (34%). The rest claimed that enhancing biodiversity would be better for soil and water protection among others. Among the respondents who did not support biodiversity, 48% of them claimed that understorey affected the growth of the dominant tree species, 12% reported that their forests were small and therefore were not appropriate for enhancing biodiversity, and the remainder cited other reasons.

In the survey, no data about birds were obtained. Only data about understorey in planted forests were recorded because of limited budget and time. It therefore is assumed that people's conservation attitudes towards birds are similar or even more positive than their attitudes towards understorey plants. This is because birds do not compete for soil, water, and space with the dominant tree species. Moreover, it was assumed that any of the biodiversity support, understorey value, and understorey awareness variables can be a proxy for conservation attitudes since they are positively correlated. It means that saying "yes" to enhancing biodiversity, saying "yes" to understorey value, and saying "yes" to understorey awareness would be considered as positive conservation attitudes. Equally, saying "no" to these variables would reflect negative conservation attitudes.

The results show that the Spearman rank correlation coefficient between understorey value and education of the respondents is .227 ($df=269,\ p<.05$), showing that educated forest owners have more positive attitudes towards the value of understorey plants. Also, the value of understorey plants (coding: 0 is no value and 1 is having a value) and ethnicity of the respondents (coding: 0 is the Kinh group and 1 is the minority groups) is negatively correlated, -.276 ($df=269,\ p<.01$), showing that the respondents in the majority group (the Kinh group) have a more positive attitude towards conservation than the minority groups. Again, ethnicity of the respondents is also statistically correlated to the reasons given for supporting biodiversity in planted forests or not.

Further, age of forest owners and their awareness of understorey plants are negatively correlated, -.116 ($df=269,\ p<.05$), showing a more positive attitude towards conservation among young people. Moreover, the Spearman rank correlation coefficient between biodiversity support and size of planted forest is positive, .118 ($df=269$, $p<.05$). It is likely that the forest owners who possess a larger planted forest area have more positive conservation attitudes than the ones with a smaller area. This corresponds with the responses of those not supporting biodiversity in planted forests since they thought their forests were too small.

Surprisingly, financial status or poverty level (coding: well-off=1, average=2, and poor=3), and biodiversity support (coding: 0 is no support and 1 is supporting) are positively correlated, .124 ($df=269$, $p<.05$), suggesting that poorer people express more positive attitudes towards conservation. It seems that the poorer people expect to receive financial support and thus agree to enhance biodiversity. In contrast, the richer forest owners seem to be more concerned that enhancing biodiversity will affect timber productivity and result in a significant loss of profit, outweighing the financial support for biodiversity. In addition, there is no significant relationship between conservation attitudes and gender and household size.

In summary, the majority of the respondents believe that there are understorey plants in planted forests and these plants have a certain value. Also, a large number would agree to the idea of enhancing biodiversity in planted forests if they were financially supported. The findings of this study show that more educated, younger, and poorer people as well as those who belong to Kinh group, and possess larger areas of planted forests have more positive attitudes towards the biodiversity conservation.

4.3 TIMBER AND CARBON OPTIMIZATION MODELS

This section presents the results regarding the optimal rotation ages and the NPVs obtained from both the timber and the carbon optimization models. The results of the sensitivity analyses of the optimal rotation ages to carbon price, carbon payment scheme, planting cost subsidy, timber price, carbon sequestration function, and economies of planting scale are also presented. Discussion of the results are provided in this section.

4.3.1 The optimal rotation age at stand level

This section presents the optimal rotation ages for timber only and carbon models for both *Eucalyptus urophylla* and *Acacia mangium* at a stand level. The results are based on the assumptions of a carbon price equal to 0.051 million VND/m^3 or 3 USD/m^3, and a timber price of 0.37 millionVND/m^3 for *Eucalyptus urophylla* and 0.33 millionVND/m^3 for *Acacia mangium*. The study uses an 8% discount rate for households and a 6% for enterprises as discussed in section 3.4.2. The results for the optimal rotation lengths and their associated NPVs, as well as a sensitivity analysis with regard to the discount rate are presented in Table 4.6 and Table 4.7.

Table 4.6 Stand level rotation ages for timber only and carbon values for *Eucalyptus urophylla* in forest households and enterprises*

Discount rate (%)	Households				Enterprises			
	Timber only		With Carbon		Timber only		With Carbon	
	T (years)	NPV (m. VND/ha)	T	NPV	T	NPV	T	NPV
1	10	51.97	10	64.44	10	170.52	10	189.85
2	10	38.17	10	47.82	10	126.86	10	141.81
3	10	28.41	10	36.03	10	95.87	10	107.68
4	10	21.36	10	27.49	10	73.42	10	82.92
5	10	16.15	**9**	21.24	9	56.86	9	65.17
6	10	12.24	**9**	16.68	9	44.90	9	51.84
7	9	9.36	9	13.15	9	35.61	9	41.48
8	9	7.10	9	10.35	9	28.25	9	33.29
9	9	5.29	8	8.15	9	22.35	**8**	27.04
10	9	3.81	8	6.42	8	17.78	8	21.95

Note: * Carbon price: 0.051 million VND/m^3 or 3 USD/m^3, timber price: 0.37 millionVND/m^3.

According to Table 4.6, at the chosen discount rates, the timber rotation age for *Eucalyptus urophylla* is 9 years for both households and enterprises. Adding carbon benefits has no effect on the rotation age for *Eucalyptus urophylla* for both households and enterprises. This is because both the rates of carbon uptake and of timber growth are faster in early years, however, the latter rate is much faster, making the optimal rotation age remain the same (i.e. the carbon sequestration rate is low so that it does not change the optimal rotation age). The NPV for enterprises is at least five times higher than that for households. For example, the timber only NPV is 7.1 and 44.9 million VND per ha for households and enterprises, respectively.

Table 4.7 Stand level rotation ages for timber only and carbon values for *Acacia mangium* in forest households and enterprises*

Discount rate (%)	**Households**				**Enterprises**			
	Timber only		With **C**arbon		Timber only		With Carbon	
	T (years)	NPV (m. VND/ha)	T	NPV	T	NPV	T	NPV
1	17	59.95	17	75.65	17	195.76	17	209.71
2	17	42.60	13	55.22	17	141.63	13	153.24
3	17	30.51	13	41.19	13	105.76	13	115.57
4	13	22.34	13	31.06	13	80.58	13	88.33
5	13	16.60	10	24.11	13	62.00	10	68.52

6	13	12.30	10	18.87	11	48.23	10	54.53
7	13	9.01	10	14.83	10	38.27	10	43.73
8	11	6.55	9	11.71	10	30.59	10	35.26
9	11	4.67	9	9.29	10	24.46	9	28.51
10	10	3.15	9	7.32	10	19.49	9	23.27

Note: *Carbon price: 0.051 millionVND/m^3 or USD 3/m^3, timber price: 0.33 millionVND/m^3.

As shown in Table 4.7, the timber rotation age for *Acacia mangium* is 11 years for both types of ownership at the chosen discount rate. When carbon sequestration has a price of 3 USD/metric tonne, the carbon rotation age for *Acacia mangium* is shorter by 2 years in the case of households, and remains the same in the case of enterprises. This is because of the fact that higher timber productivity outweighs the effect of carbon sequestration on the optimal rotation age for enterprise planted forests. The carbon rotation age for *Acacia mangium* for enterprises (i.e. 10 years) is longer than that for households (i.e. 9 years). Similar to the case of *Eucalyptus urophylla*, the NPV for enterprises are much higher than that for households as a result of the higher timber productivity of the enterprises.

The optimal timber and carbon rotation ages for *Eucalyptus urophylla* and *Acacia mangium* (from 9 to 11 years) are shorter than their maximum annual increments (from 15 to 81 years) as presented in sections 3.5.1 and 3.5.2. The maximum annual increments for timber growth and carbon sequestration for *Acacia mangium* (47 and 81 years, respectively) are well above those for *Eucalyptus urophylla* (15 and 42 years, respectively). Hence, at a given discount rate, the optimal rotation ages for *Acacia mangium* are longer than those for *Eucalyptus urophylla*.

The results of a sensitivity analysis of the optimal rotation age to discount rates are also shown in Table 4.6 and Table 4.7. At positive discount rates, the optimal rotation length for *Eucalyptus urophylla* ranges from 8 to 10 years for both households and enterprises with hardly any difference between the two except at discount rates 5% and higher when the optimal rotation age for carbon becomes slightly shorter than the optimal timber rotation age. For *Acacia mangium*, the optimal timber rotation age varies from 9 to 17 years depending on the discount rates and with the carbon optimal rotation being shorter by several years especially at lower discount rates (1–5%). Both the timber and carbon optimal rotation ages decrease with an increasing discount rate.

In terms of NPV, the carbon rotations all have higher NPVs as is to be expected with carbon having a value (Table 4.6 and Table 4.7). The NPV values for enterprises are also higher than for households. This result follows from earlier discussion, which indicated that households, whose land is allocated by the Government, tend to plant trees with higher density, use less fertilizers and may apply incorrect growing techniques.

The finding that the optimal carbon rotation is shorter than the timber only rotation (more so for *Acacia mangium* than for *Eucalyptus urophylla*) is in constrast to the result of van Kooten et al. (1995) and Gutrich and Howarth (2007). This is because of the nature of fast-growing trees in this study, where carbon uptake and timber growth are greater in early years compared to the slow-growing tree species in the analysis in the two studies mentioned. This difference can be shown by looking at the first derivatives of the timber growth functions and carbon sequestration functions used in those studies (Appendix 1).

In our analysis, the faster growth and sequestration makes it optimal to cut and replant trees sooner to maximize profit from selling timber and collect the carbon sequestration value. Our results are in line with the findings of Hartman (1976) that the incorporation of non-timber benefits associated with young forests induces a shorter rotation age compared to the Faustmann one. In addition, the relationship between the optimal rotation age and the discount rate agrees with the literature.

Given the results of the survey (Table 4.1), which show that actual harvesting age for households is 5 years and for enterprises 7 years, the optimal results obtained in this analysis all show longer rotations at all discount rates. This result indicates that policy intervention is needed to bring the actual harvesting age in line with the optimal rotation age. This will be further discussed in the section of policy analysis followed later in this chapter.

4.3.2 The optimal rotation age at forest level

This section presents the timber only and carbon optimal rotation ages at a forest level for *Eucalyptus urophylla* for household forest owners. The optimization models at a forest level are not applied to the case of *Acacia mangium* because its planting cost function does not show economies of scale. The models are also not applied to enterprise planted forests, since a planting cost function for them does not exist as mentioned in section 4.2.2.

To estimate forest level rotation, 5 case studies for *Eucalyptus urophylla* are randomly chosen from the survey data by using Microsoft Excel (Table 4.8). Since the number of stands ranges between 1 and 5 in the survey database, one case with 2, 4, and 5 stands; and two cases with 3 stands are selected. In each case, two situations are analysed: (1) zero initial ages for all stands and (2) actual initial ages. Forest stand areas are the actual households' stand areas from the survey.

Table 4.8 Case studies used for the forest level models for *Eucalyptus urophylla*

Cases	Codes*	No. of stands	Area of stands (ha)					Age of stands (years)				
			S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
1	A086	5	3.1	2.9	1	0.8	0.8	3	3	3	3	3
2	A086	5	3.1	2.9	1	0.8	0.8	0	0	0	0	0
3	A075	4	1	0.3	0	0.3	…	4	2	2	2	…
4	A075	4	1	0.3	0	0.3	…	0	0	0	0	…
5	A038	3	3	1	1	…	…	1	1	1	…	…
6	A038	3	3	1	1	…	…	0	0	0	…	…
7	A017	3	2	0.5	1	…	…	2	1	1	…	…
8	A017	3	2	0.5	1	…	…	0	0	0	…	…
9	A007	2	1	1	…	…	…	4	2	…	…	…
10	A007	2	1	1	…	…	…	0	0	…	…	…

Note: * This is coding number used in the survey database.

The timber only and carbon optimal rotation ages at a forest level for *Eucalyptus urophylla* for households are shown in Table 4.9. The inclusion of a carbon value, when the initial age equals zero, shortens the rotation age from 9 to 8 years. Comparing the rotation age at the forest level (i.e. economies of scale is included) with the stand level (i.e. economies of scale is not included) shows that the timber optimal rotation age, when the initial age is greater than zero, is shorter than that at a stand level by one year (Table 4.6). In contrast, the carbon rotation age at a forest level is shorter by one year, regardless of the initial age.

These results show that the economies of planting scale as well as the initial age and the carbon value affect the timing of tree cutting decisions. It is expected that the optimal rotation age would be significantly affected by economies of scale if the average forest area was larger than it is at the moment (3.95 ha); and by the carbon value if carbon price was higher. Further, the optimal rotation age would not be significantly influenced by the initial age of forests, which is up to 7 years, if the planning horizon was much longer (200 years, for example) than 50 years. Because if the initial age of the forest is greater than zero, it will contribute significantly to the NPV of the forest (because of the discount rate effects). However, if the planning horizon is longer, it will reduce the contribution of the initial age to the NPV proportionally.

Table 4.9 Forest level rotation ages with timber only and carbon values for *Eucalyptus urophylla**

Case	Timber only		Carbon	
	T (years)	NPV (m.VND/ha)	T	NPV
1	8	12.16	8	15.93
2	9	8.64	8	11.47
3	8	12.08	8	15.93
4	9	8.34	8	11.14
5	8	9.52	8	12.75
6	9	8.55	8	11.37
7	8	10.07	8	13.44
8	9	8.48	8	11.30
9	8	11.79	8	15.57
10	9	8.38	8	11.19

Note: *Carbon price: 0.051 millionVND/m^3 or USD 3/m^3, timber price: 0.37 millionVND/m^3, discount rate: 8%.

Regarding NPV, the NPVs for timber only and carbon models at a forest level (Table 4.9) are greater than those at a stand level (Table 4.6). At an 8% discount rate, the stand level NPVs are 7.10 and 10.35 million VND/ha for timber only and carbon models, respectively. In contrast, the forest level NPVs range from 8.34 to 12.16 million VND/ha for the timber only model, and from 11.14 to 15.93 million VND/ha for the carbon model. This result shows that the economies of planting scale have positive impacts on the profitability of forests. In other words, merging small forest stands will bring about a higher profit. This is in line with the literature that planted forests that are managed at a larger scale will be more profitable (Lien, Størdal, & Baardsen, 2007; Termansen, 2007).

4.3.3 Sensitivity analysis to carbon price

This section presents the results of a sensitivity analysis of the stand level models to different values for the carbon price. The carbon price varies from 3 to 10 USD (equivalent to 0.051 to 0.17 million VND) per metric tonne. The results are summarized in Table 4.10 for *Eucalyptus urophylla* and in Table 4.11 for *Acacia mangium*.

Table 4.10 Sensitivity analysis of the stand level carbon rotation age to carbon price for *Eucalyptus urophylla* in household and enterprise forests

Carbon price (USD/tonne)	**Households**		**Enterprises**	
	T (year)	NPV (m. VND/ha)	T	NPV
3 (0.051 m.VND)	9	10.35	9	33.29
4 (0.07)	9	11.56	8	35.25
6 (0.10)	8	13.62	8	38.45
8 (0.13)	8	15.68	8	41.65
10 (0.17)	8	18.43	8	45.92

In the case of *Eucalyptus urophylla* (Table 4.10), the carbon rotation age decreases slightly with an increasing carbon price, from 9 to 8 years. At the carbon price of 4 USD per metric tonne, the households carbon rotation age is one year longer than that of enterprises. At other carbon prices, the carbon rotation ages for both types of ownership are similar. The NPVs for carbon rotation age, for both types of ownership, increase with an increasing carbon price as expected.

Table 4.11 Sensitivity analysis of Faustmann rotation age to carbon price for *Acacia mangium* in forest households and enterprises

Carbon price (USD/ton)	Households		Enterprises	
	T (year)	NPV (m. VND/ha)	T	NPV
3 (0.051 m.VND)	9	11.71	10	35.26
4 (0.07)	9	13.90	10	36.99
6 (0.10)	7	17.96	9	39.96
8 (0.13)	6	22.89	9	43.05
10 (0.17)	3	31.84	8	47.31

As shown in Table 4.11, *Acacia mangium* experiences a similar relationship between the carbon rotation age and the carbon price as found with *Eucalyptus urophylla.* The households' rotation age for *Acacia mangium* is very sensitive to carbon price, decreasing from 9 to 3 years with an increasing carbon price; showing that carbon sequestration has an significant impact on the optimal rotation age. The NPVs for carbon rotation age, for both species and both types of ownership, increase with an increasing carbon price as expected.

The relationship found between rotation length and carbon price stands in contrast to the findings of van Kooten et al. (1995), but is in agreement with the results of Englin and Callaway (with amenity value) (1993). Diaz-Balteiro and Rodriguez (2006) found that carbon price level has little effect with no clear pattern on the rotation length. The reasons for different relationships between rotation length and carbon price can be again explained by the carbon sequestration functions used in these studies. As discussed earlier, this study employed the carbon sequestration functions that have a rapid take-up of carbon in early years, making it optimal to harvest the trees sooner as the carbon price increases.

4.3.4 Sensitivity analysis to carbon payment scheme

The impacts of various carbon payment schemes on the optimal management strategy are presented in Table 4.12. Carbon value (with a carbon price of 0.051 million VND/m^3 or 3 USD/m^3) can be paid to forest owners at the beginning of the rotation. To be eligible for receiving carbon payment at the start of the rotation, forest owners would have to commit to keep the trees till the end of the rotation. Alternatively, the carbon payment can be paid every year, or at the end of the rotation.

Table 4.12 The carbon rotation age at stand level with carbon payment scheme

Species	Ending payment		Annual payment		Beginning payment	
	T (year)	NPV (m. VND/ha)	T	NPV	T	NPV
Eucalyptus urophylla	9	10.35	9	11.94	9	13.09
Acacia mangium	9	11.71	10	15.73	10	16.90

Table 4.12 shows that payment schemes have no significant impact on the rotation age. In particular, the optimal rotation age remains the same at 9 years in all

payment schemes for *Eucalyptus urophylla*. The optimal rotation age for *Acacia mangium* is 9 years in the ending payment scheme, and is 10 years for the other two schemes. However, the payment schemes have an impact on the NPV. A lump-sum payment at the beginning of the rotation increases the NPV slightly compared to annual payment and payment at the end of the rotation.

4.3.5 Sensitivity analysis for a changing planting cost subsidy

The results of a sensitivity analysis of the carbon rotation age to a planting cost subsidy are reported in Table 4.13 and Table 4.14. Since planting costs for both species are around 6 million VND, a subsidy level between 0.5 and 6.77/6.85 (i.e. planting costs of two species) million VND per ha per rotation is used. The results show that the larger the planting cost subsidy, the shorter the rotation age.

Table 4.13 Sensitivity analysis of the carbon rotation age at stand level with the planting cost subsidy for *Eucalyptus urophylla*

Subsidy level (m. VND/ha)	**T (year)**	**NPV (m. VND/ha)**
6.85	6	25.91
4	7	18.96
2	8	14.54
1	8	12.39
0.5	9	11.33

As shown in Table 4.13, for *Eucalyptus urophylla*, the carbon rotation age decreases from 9 to 6 years with an increase in the planting cost subsidy. The NPV increases from 11.33 to 25.91 million VND per ha. The NPV shows a more significant change in size (double its value) than the change in the optimal rotation age.

Table 4.14 Sensitivity analysis of Faustmann carbon rotation age with the planting cost subsidy for *Acacia mangium*

Subsidy level (m. VND/ha)	T (year)	NPV (m. VND/ha)
6.77	5	27.55
4	7	20.15
2	8	15.69
1	9	13.68
0.5	9	12.69

For *Acacia mangium* (Table 4.14), the rotation age is reduced significantly, from 9 to 5 years, with an increase in the subsidy. This result means that as the planting cost is getting smaller because of the subsidy, forest owners tend to harvest the trees sooner in order to maximize their profit. The relationship between the rotation age and planting cost is similar to that of the Faustmann model. The NPVs for both species are higher with the higher subsidy level as expected.

4.3.6 Sensitivity analysis to timber price

This section presents a sensitivity analysis of the optimal carbon rotation age to different levels of timber price. The results are shown in Figure 4.3 and Figure 4.4. The timber price that is used in the analysis of this section is a timber price that varies with timber size.

Timber of different sizes is sold at different prices, thus, a timber price varying with timber size is employed. Harvest size of timber is assumed to be positively correlated to timber age. Assumptions are also based on the preliminary fieldwork and the interviews during the survey as follows. Let harvest age and the price of timber aged 7 be *T* and *P*, respectively. Then, *P* is 0.37 m. VND/m^3 for *Eucalyptus urophylla* and 0.33 for *Acacia mangium*. Let the price of timber, which is harvested at any age *T*, be P_t as follows.

$$P_t = \begin{cases} P - 0.15 : \mathit{for}\, T < 5 \\ P - 0.05(7 - T) : \mathit{for}\ 5 \le T \le 6 \\ P : \mathit{for}\, T = 7 \\ P + 0.1(T - 7) : \mathit{for}\ 7 < T \le 14 \\ P + 0.8 : \mathit{for}\, T > 14 \end{cases}$$

The price of timber (*P*) is varied from 0.1 to 3 m. VND/m^3 for a sensitivity analysis.

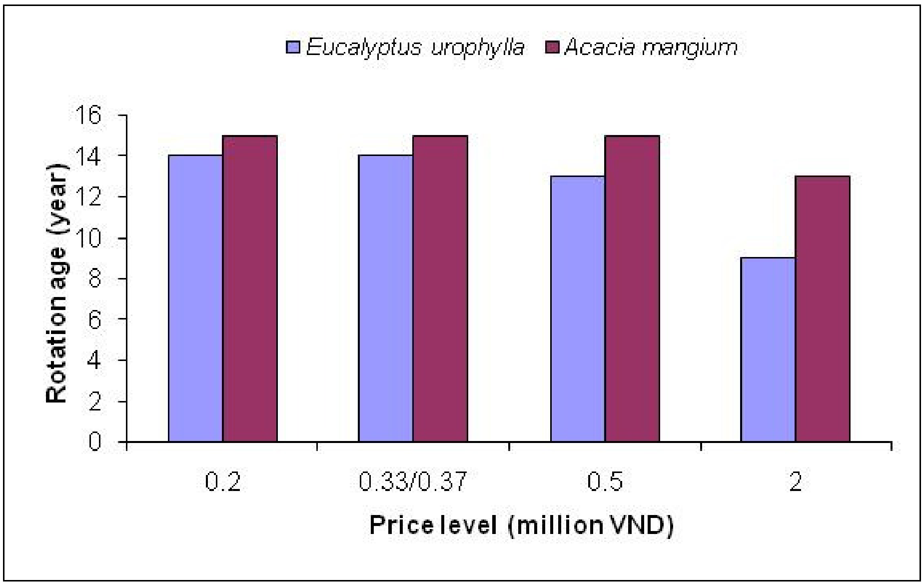


Figure 4.3 Sensitivity analysis of the carbon rotation age at a stand level to timber price when timber price is varied with timber size

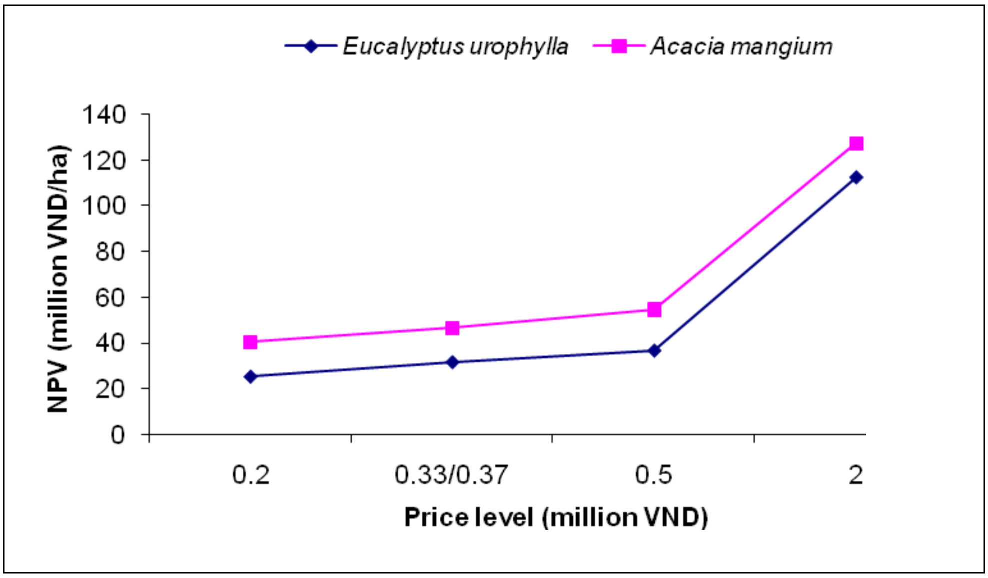


Figure 4.4 Sensitivity analysis of the carbon NPV to timber price when timber price is varied with timber size

Figure 4.3 shows that a varying timber price (*P*) makes the rotation ages, 14 years for *Eucalyptus urophylla* and 15 years for *Acacia mangium*, significantly longer compared to those of a constant price, 9 and 11 years, respectively. This means that when different prices for timber size (i.e. higher prices for bigger timber) are considered, it is optimal for forest owners to grow large-size timber (to delay their harvest beyond 10 years).

Figure 4.3 also shows that the optimal rotation age decreases, from 14 to 9 years for *Eucalyptus urophylla* and from 15 to 13 years for *Acacia mangium*, with an increase in the timber price (*P*). This trend is similar to that of the Faustmann model; as timber price increases, it is optimal to harvest the trees sooner and replant them in order to maximize profit. The NPV increases with an increasing timber price as expected (Figure 4.4).

In conclusion, the results show that a varying timber price makes the optimal rotation ages significantly longer compared to those of a constant price. The varying timber price is a more realistic assumption compared to a constant price; however, it is not applied to the whole analysis because of great uncertainty in the timber price functions. In particular, assumptions made to derive the timber price functions are based on personal communications in the preliminary fieldwork and the survey, not from the survey questionnaires.

4.3.7 Sensitivity analysis to carbon sequestration functions

As mentioned in section 2.1.2, the impacts of three different carbon functions, i.e. equations (25) and (26), on the rotation length are analysed for *Eucalyptus urophylla.* These equations are taken from the study of Vo et al. (2009). The results are shown in Table 4.15 for the stand level model.

Table 4.15 Sensitivity to carbon sequestration function at stand level for *Eucalyptus urophylla*

Equations	T (year)	NPV (million VND/ha)
(21) Used in the analysis	9	10.35
(25)	9	9.16
(26)	8	11.58

As shown in section 4.3.1, the incorporation of carbon benefits, using equations (21) and (22) for carbon uptake encourages a shorter rotation age compared to the timber rotation age. Table 4.15 shows that using equation (25) for carbon sequestration does not change the timber optimal rotation age (i.e. remaining at 9 years). The reason is that the pattern of carbon sequestering in this equation and timber growth are nearly similar. Equation (26), however, makes the rotation age slightly shorter. In this equation, the total amount of carbon uptake increases with the age and it sequesters significantly more in its early life (i.e. the function is increasing at a decreasing rate). This explains why the rotation age is shorter.

4.3.8 Sensitivity analysis to economies of planting scale

At the forest level, a sensitivity analysis is performed with regard to economies of scale in planting by varying λ of the timber planting cost function for *Eucalyptus urophylla* - equation (27). The results for the optimal timber rotation age are presented in Table 4.16. The results of the carbon rotation age are provided in Figure 4.5.

Table 4.16 Sensitivity of the timber optimal rotation to λ at forest level for *Eucalyptus urophylla*

Case No.	T (year)		NPV (million VND/ha)	
	λ =0.6	0.98	λ =0.6	0.98
1	8	8	18.3	12.2
2	8	9	13.9	8.6
3	8	8	12.4	12.1
4	9	9	9.9	8.3
5	8	8	14.2	9.5
6	8	9	12.9	8.5
7	8	8	13.1	10.1
8	8	9	12.1	8.5
9	8	8	13.0	11.8
10	9	9	10.5	8.4

As shown in Table 4.16, when only timber has a value, a lower value of λ shortens the rotation age in some cases. For example, in cases 2, 6, and 8, the rotation age is shortened by one year from 9 years as λ decreases from 0.98 to 0.6. This is likely because the size of forests and the number of forest stands are small, economies of scale in planting has little impact on the optimal rotation age. However, economies of scale increases the NPV in all ten cases (Table 4.8).

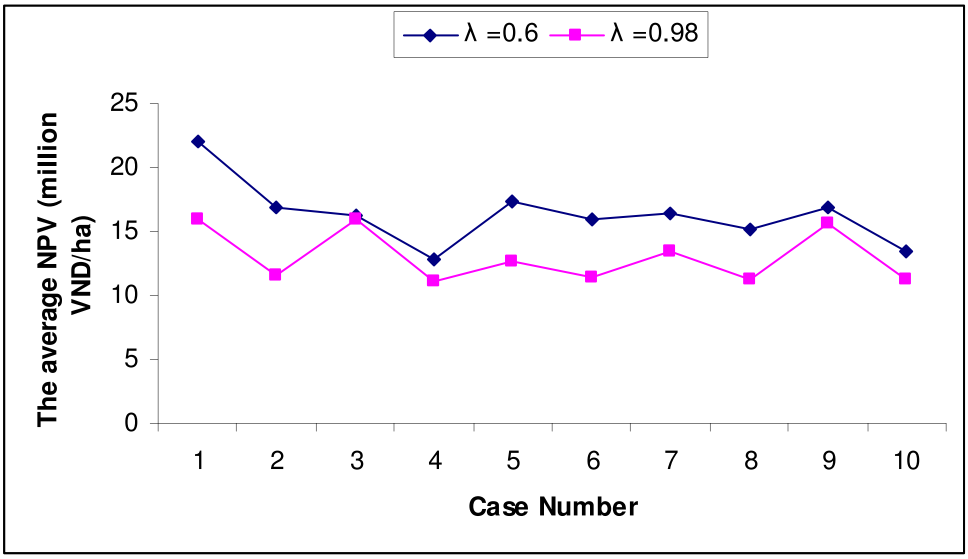


Figure 4.5 Sensitivity of the carbon optimal rotation to λ at forest level for *Eucalyptus urophylla*

When carbon value is included, a lower value of λ has no impact on the carbon rotation age (it remains at 8 years). In contrast, a lower value of λ increases the NPV significantly (Figure 4.5). In conclusion, economies of scale has no significant impact on the rotation ages for both timber only and carbon models. However, it does increase the NPVs for both situations.

4.4 BIODIVERSITY OPTIMIZATION MODEL

This section examines whether adding a biodiversity constraint to the optimization model does alter the optimal rotation ages compared to the timber and carbon rotation ages. The results from a sensitivity analysis of the rotation age to the biodiversity constraint, discount rate, timber price, and carbon price are also presented. The section also provides discussion of these results.

4.4.1 The optimal rotation age

The biodiversity optimization model described in section 3.3.3 is applied to the ten case studies at a forest level, which were randomly chosen from a pool of 271 households in the survey sample conducted in Yen Bai province, Vietnam. The objective of this model is to maximize the NPV from selling timber and sequestering carbon, while subject to a minimum population of birds over a 50-year planning horizon. The biodiversity rotation age, and its associated NPV and the number of birds are presented in Table 4.17.

Table 4.17 The optimal results of all cases at an 8% discount rate and the 50 MVP for *Eucalyptus urophylla*

Case	Initial age of all stands	No of Stands	Total forest size	MVP =0			MVP =50		
				T	NPV[a]	Birds[b]	T	NPV	Birds
1	15	5	8.6	8	15.93	42	11	13.97	54
2	0	5	8.6	8	11.47	41	11	9.95	53
3	10	4	1.6	8	15.93	43	10	15.14	50
4	0	4	1.6	8	11.14	41	11	9.68	53
5	3	3	5	8	12.75	41	11	11.06	54

6	0	3	5	8	11.37	41	11	9.87	53
7	4	3	3.5	8	13.44	41	11	11.69	54
8	0	3	3.5	8	11.30	41	11	9.81	53
9	6	2	2	8	15.57	42	11	13.70	54
10	0	2	2	8	11.19	41	11	9.71	53

[a]: average million VND per ha
[b]: average individuals per year per ha

The results in Table 4.17 show that the inclusion of the MVP into the optimization model leads to a longer rotation age compared to the timber and carbon rotation ages. For all ten cases, the timber rotation age is between 8 and 9 years (Table 4.9). As shown by Table 4.17, the carbon rotation age (when the MVP is 0 bird per ha per year) is 8 years, while the biodiversity rotation age (when the MVP is 50) is between 10 to 11 years.

Table 4.17 also shows that, for all ten cases, the biodiversity rotation age, on average, goes up from 8 to 10.9 years, by 2.9 years or 36%, with a rise in the MVP. As the MVP constraint increases from 0 to 50 individuals, the number of birds rises from a minimum of 41 to a maximum of 54 individuals per ha per year, or approximately by 20%. The biodiversity constraint does cause the NPV to go down, from a maximum of 15.93 to 9.68 million VND per ha with a rise in the MVP.

According to the results, by lengthening the rotation age (36%), we could gain a significant increase in the number of birds (28%), which means more biodiversity and more supply of large-size timber for the Vietnam market, with a relatively small decrease in the NPV (12%). This result (the incorporation of biodiversity preservation lengthens the optimal rotation age) is in line with the findings by Koskela, Ollikainen, and Pukkala (2007a).

4.4.2 The role of longer rotations to the enhancement of biodiversity

As discussed in section 2.3.4, longer rotations can significantly increase biodiversity by reducing the rate of timber harvest over a given planning horizon. Longer rotations result in fewer clear-cut areas per decade, and thus contribute to the succession of species which is sensitive to the proportion of recently disturbed landscapes. Increasing rotation age allows more time for organisms to become re-established after clear-cut and provides a habitat for species that depend on old-growth forests.

This study shows that longer rotations lead to more diverse age classes and increase the area of old-growth forest stands within a forest at a given time horizon. To do that, a simulation is done in MSExcel using forest data (initial ages and stand areas) from case 1, 3, and 6 (see Table 4.8). Classification of forest stands is made based on the survey results for forest enterprises in Yen Bai province and Decision No. 147 by Vietnamese Government (Vietnamese Government, 2007a). In the survey, forests are normally cut at age 5-7 years. It is therefore assumed that mature stands are stands aged from 6 to 9 years. In the Decision No 147, forest stands aged 10 years and beyond are subsidized by the Government, and hence, they are considered as old-growth forest stands. In the context of planted forests with fast-growing and exotic tree species in Vietnam, forest stands aged 0 year are classified as clear-cut areas, 1 to 5 years are young, 6 to 9 are mature, and aged 10 and beyond are old-growth stands. The results of the simulation are presented in Table 4.18.

Table 4.18 Percentage of different forest stand types in the total forest area over a 50 year planning horizon

Case	Stand types	Rotation age (years)		
		5	8	11
1	Clear-cut	16	10	8
	Young	84	54	44
	Mature	0	36	32
	Old-growth	0	0	16
3	Clear-cut	17	11	8
	Young	83	54	43
	Mature	0	35	33
	Old-growth	0	0	16
6	Clear-cut	16	10	8
	Young	84	60	44
	Mature	0	30	32
	Old-growth	0	0	16

As shown in Table 4.18, lengthening rotation ages from 5 to 11 years increases the total area of old-growth forest stands over a 50 year planning horizon while reducing clear-cut area in the total forest area. In particular, the clear-cut area declines from 16 to 8% in case 1 and case 6, and from 17 to 8% in case 3. The old growth area increases from 0 to 16% in all three cases as the rotation age rises from 5 to 11 years. Since birds prefer old-growth forests (discussed in section 3.2.2), the increase in this area has lead to the increase in the number of birds as presented in the previous section (4.4.1).

4.4.3 Sensitivity analysis to the minimum viable population

To perform a sensitivity analysis of the biodiversity rotation age to different levels of the MVP, the MVP is increased from 50 to 100 average bird individuals per ha per year. The analysis is performed for all ten cases of household forests. The discount rate is 8% and the carbon price is 3 USD per metric tonne.

Table 4.19 Sensitivity analysis of the biodiversity rotation age to the MVP

Case	**T** (year)		**NPV** (million VND/ha)		**No. of Birds** (individuals per year per ha)	
	MVP=70	**100**	**MVP=70**	**100**	**MVP=70**	**100**
1	15	18	8.62	4.70	78	101
2	15	19	5.71	1.75	77	103
3	15	18	8.64	4.64	78	102
4	15	19	5.47	1.54	77	103

5	15	19	6.49	2.22	77	105
6	15	19	5.63	1.68	77	103
7	15	19	6.93	2.48	77	105
8	15	19	5.58	1.64	77	103
9	15	18	8.40	4.49	78	101
10	15	19	5.50	1.57	77	103

Table 4.19 shows that the optimal rotation age and the number of birds increase with a rise in the MVP. In contrast, the NPV decreases with an increase in the MVP. In particular, the rotation age increases from 10.9 years on average (see Table 4.17), to 15, and 18.7 years as the MVP increases. The average NPV decreases from 11.65 (see Table 4.17) to 6.7, and 2.67 million VND per ha. This means that forest owners have to give up more of their profit from selling timber and sequestering carbon for an increase in biodiversity in their forests. Finally, the number of birds rises from 53.2 to 77.3, and 102.9 individuals.

4.4.4 Sensitivity analysis to the discount rate

Table 4.20 shows the results of a sensitivity analysis of the biodiversity rotation age to the discount rate. The optimal rotation age and the number of birds slightly decrease with a rise in the discount rate from 1 to 5%, and remain constant as the discount rate goes up from 5 to 10%. It is likely that the biodiversity rotation age depends on variables, which are not influenced by the discount rate such as the number of birds.

The NPV is reduced significantly by 65−67% as the discount rate increases from 1 to 10%. In conclusion, the selection of a discount rate does not have significant impacts on rotation age and biodiversity, but does significantly affect the profitability of planted forests to forest owners.

Table 4.20 Sensitivity analysis of the biodiversity rotation age to the discount rate (MVP=50)

Case	**T** (year)			**NPV** (million VND/ha)			**No. of Birds** (individuals per year per ha)		
	r=0.01	**0.05**	**0.1**	**r=0.01**	**0.05**	**0.1**	**r=0.01**	**0.05**	**0.1**
1	13	11	11	65.59	25.16	9.71	65	54	54
2	12	11	11	62.79	20.56	6.02	58	53	53
3	10	10	10	69.15	26.58	10.83	50	50	50
4	12	11	11	62.23	20.20	5.78	58	53	53
5	12	11	11	64.14	21.74	7.04	59	54	54
6	12	11	11	62.61	20.45	5.94	58	53	53
7	12	11	11	64.61	22.36	7.64	60	54	54
8	12	11	11	62.49	20.37	5.89	58	53	53
9	13	11	11	64.83	24.75	9.50	65	54	54

10	12	11	11	62.30	20.25	5.81	58	53	53

In this study, a similar discount rate is applied to both timber production and carbon sequestration. This assumption implies that carbon sequestration is also considered as a private good. The practice of discounting both timber products and carbon uptakes using a private discount rate is popular in numerous studies (Bateman & Lovett, 2000). On the other hand, the use of a social discount rate only for the carbon sequestration services has been suggested by some studies (Richards & Stokes, 2004). However, there is also no reliable global social discount rate useful for carbon sequestration analysis (Diaz-Balteiro & Rodriguez, 2006).

4.4.5 Sensitivity analysis to the carbon price

Figure 4.6 shows the results of a sensitivity analysis of the biodiversity rotation age to carbon price. The biodiversity rotation age and the number of birds remain constant as carbon price goes up, but increasing the NPV. The results show that the increase in carbon price has no effect on the biodiversity rotation age, but a greater profit to forest owners.

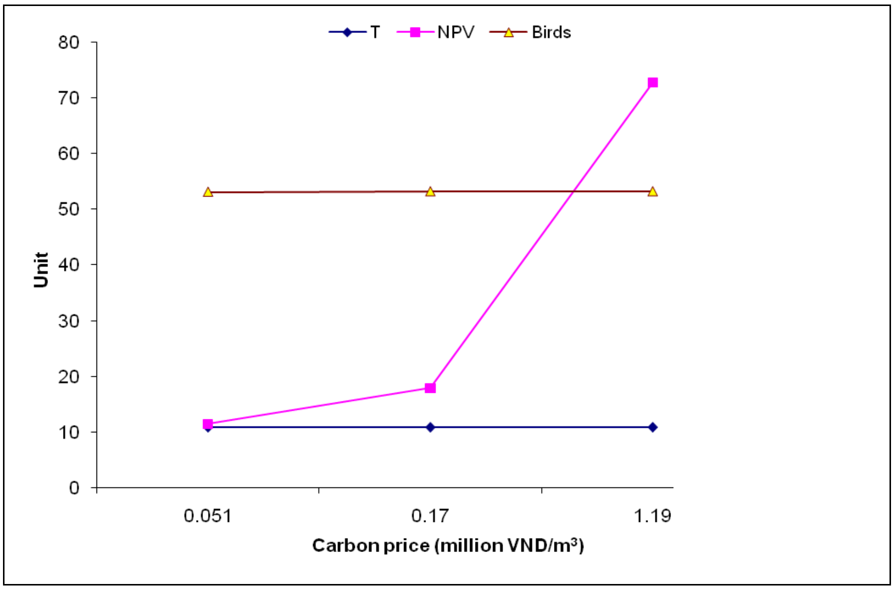


Figure 4.6 Sensitivity analysis of the biodiversity rotation age to carbon price

Also shown in Figure 4.6, when the carbon price goes up, the biodiversity rotation age is still above 10 years, while the carbon rotation age reported in Table 4.10 may be as short as 8 years. This is because the biodiversity constraint acts as a lower bound for the biodiversity rotation age. As a result, at a 0.17 million VND carbon price (10 USD/tonne), the NPV is 17.86 million VND per ha for the biodiversity rotation and lower than that for the carbon rotation (18.43 million VND per ha, Table 4.10). This implies that as the carbon price increases, forest owners who enhance biodiversity in their forests will lose more money from the provision of carbon uptake than ones who do not.

4.4.6 Sensitivity analysis to the timber price

The results of the sensitivity analysis of the biodiversity rotation age to changing timber prices (from 0.37, 0.5 and 2 million VND per m^3) are presented in Table 4.21. The change in the rotation age to a rise in the timber price is similar to the one with an increase in the carbon price. At an 8% discount rate, the rotation age (from 10 to 11 years, Table 4.17) and the number of birds (from 50 to 54 individuals, Table 4.17) remain constant with a rise in the timber price. The rotation age and the number of birds are again determined by the MVP constraint.

Table 4.21 Sensitivity analysis of the biodiversity rotation age to timber price

Case	NPV (million VND/ha)		
	P=0.37	**0.5**	**2**
1	13.97	20.93	101.22
2	9.95	15.44	78.77
3	15.14	22.77	110.81
4	9.68	15.16	78.49
5	11.06	16.99	85.38
6	9.87	15.35	78.68
7	11.69	17.89	89.41
8	9.81	15.30	78.62
9	13.70	20.67	101.19
10	9.71	15.20	78.53

Table 4.21 also shows that, in this experiment, only the NPV increases with a rise in the timber price. The increase in the NPV is significantly larger (in proportion) than the rise in the timber price.

4.5 POLICY ANALYSIS

This section provides an analysis of a suitable policy tool to bring the optimal rotation age from a private point of view in line with that from a social perspective. The section presents the results of the optimal level of direct payments needed to induce forest owners to apply socially optimal forest management. In the sections that follow various policy tools will be discussed and the most suitable tool to apply in the context of planted forests in Vietnam will be chosen.

4.5.1 The optimal levels of direct payments

This study assumes that while private forest owners take into account the value of timber production and carbon sequestration (if carbon has a price), social managers will consider the same values as well as the value of biodiversity maintenance in harvesting decisions (as discussed in section 3.3.4). Moreover, it is also assumed that private forest owners will receive a direct payment *DP* VND/ha/year from year 4 onwards as long as their trees remain in forests. The results of the optimal level of direct payments needed to induce forest owners to apply socially optimal forest management are presented in Table 4.22.

Table 4.22 The optimal annual direct payments required to equate private and social rotation ages

Case	Optimal payment (mil. VND ha^{-1} $year^{-1}$)	T* private (year)	T* social (year)
1	0.6	8	11
2	0.6	8	11
3	0.52	8	10
4	0.59	8	11
5	0.6	8	11
6	0.59	8	11
7	0.6	8	11
8	0.59	8	11
9	0.12	8	11
10	0.59	8	11

According to Table 4.22, the optimal levels of direct payments range from 0.12 and 0.6 million VND/ha/year. On average, the optimal payment level required to equate private and social rotation ages is 0.54 million VND/ha/year. This optimal payment level is needed to extend the average optimal rotation age from 8 to 10.9 years.

4.5.2 The analysis of the forest policy tools

The success of a policy tool to achieve the desired behaviour depends not only on the characteristics of the forest benefits, such as rivalry and excludability, but also on the socio-economic conditions of the target population. As mentioned earlier, forest owners in Yen Bai province, in particular, and in Vietnam, in general, are perceived as poor and less educated people. They depend on their forests as a major source of livelihood and have limited access to modern technology, machines and facilities. They often live in mountainous areas where poor infrastructure impedes their contact with other people inside and outside the region. Hence, choosing an appropriate policy tool must take into account these conditions. This section discusses the policy tools most suitable to enhance biodiversity in planted forests in Vietnam.

As discussed, regulations would be most suitable when there is high risk associated with certain behaviours (e.g. timber harvesting in endangered species habitat) or when the behaviour is of high importance (e.g. reforestation policies) or when it is public land (Guldin, 2003; Janota & Broussard, 2008; Sterner, 2003). Regulations may be not suitable to apply to extending rotation age in households' planted forests in Vietnam for two main reasons. The first reason is that regulations can suffer from poor enforcement, especially where governance and state institutions are weak, in developing countries (Engel, Pagiola, & Wunder, 2008; Forneri, Blaser, Jotzo, & Robledo, 2006). The Vietnamese Government has difficulties in controlling logging even on state forest lands, with 12% of households committing illegal logging in Vietnam (McElwee, 2004). Thus, it is unlikely that the government will succeed in controlling logging on private lands.

The second reason is that the success of regulations worldwide positively correlates with income per capita (Dasgupta, et al., 2001), but forest owners in Yen Bai province are poor. For poor communities, imposing restrictions on their use of forest resources can create economic hardship and may induce social conflict (Bulte & Engel, 2006). In addition, the survey results show that some forest owners may harvest sooner than the time committed to (in a carbon pooling arrangement) because they are poor. Hence, for the reasons presented, regulations may fail to force the target population to lengthen timber rotation ages.

Taxes to lengthen rotation age and biodiversity offsets are not appropriate tools to enhance biodiversity in the situation here. Since forest owners are very poor and their profit from the sale of timber may not even be enough for their daily basic needs, taxes would increase their financial burden. With respect to biodiversity offsets, planted forests possess less biodiversity than natural forests or protected areas, but richer biodiversity than any other types of land uses. Thus, biodiversity offsets would be suitable tools if the land cleared for planting trees was a protected area or a natural forest. Otherwise, biodiversity offsets are not appropriate tools.

Education tools while having positive effects on encouraging forest owners to apply sustainable harvesting practices are likely to be weak policy tools in this situation. As mentioned, forest owners here are very poor, they harvest the trees at 5 years to pay for their daily basic needs. Even though they know that delaying harvest will bring about higher profit in the future as well as environmental benefits, they cannot afford to delay harvest.

Forest certifications targeting at biodiversity conservation would be a good policy tool to be employed in the future because it brings higher timber price with an expanding market. Forest certifications can also help to create environmental friendly timber products. However, there are many procedures involved and it is costly for forest household owners to get their forests certified (Durst, McKenzie, Brown, & Appanah, 2006).

Bird and butterfly farming would be a good idea to enhance biodiversity while creating jobs and also combating poverty. In this case, bird farming (an artificial way to increase the number of birds) in planted forests would help to increase biodiversity without having to lengthen a rotation age (a natural way to increase the number of birds). The issues, however, are to train farmers to raise birds and butterflies, which can take a lot of time and money. Moreover, a market for butterfly products also needs to be established. If ecotourism is chosen as a market for bird farming, then tourist areas need to be established as well. These issues cannot be addressed overnight and there is a difficulty in applying this on a large scale (for example, at a province or a state level). As discussed in section 2.4.9, butterfly farming and ecotourism are often funded by the international organizations because they are usually established in a protected area or a natural forest. In this case, however, planted forests are not biodiversity hotspots, and hence will pose more difficulty in attracting funding from international organizations for conducting butterfly farming and ecotourism.

Given the poverty of forest owners and the direct effect on biodiversity of direct payments, a more suitable approach is to pay forest owners for lengthening rotation ages. Biodiversity conservation needs to be established through "tangible incentives, not through wishful thinking that poor people will make substantial sacrifices in the short term for uncertain future rewards or for the benefit to the whole national or global community" (Ferraro & Kiss, 2003). Lower income people may favour monetary incentive tools, as their financial status may be prohibitive to otherwise engaging in forest conservation practices (Schaaf & Broussard, 2006).

When economic factors are key determinants of decisions, influencing those behaviours requires activities that change the underlying economic benefits, such as changes in economic incentives (Byers, 2000). The survey in Yen Bai province shows that family financial status of the forest owners, i.e. poor, is one of the main reasons to harvest trees sooner. Hence, providing the forest owners with monetary incentives can change their harvesting decisions, i.e. delaying harvest. The survey also shows that almost all the forest owners would agree to lengthen rotation ages if they were supported financially (section 4.2.3).

4.5.3 The analysis of direct payments

This section discusses direct payments as a policy tool to encourage household forest owners to adopt the biodiversity optimal rotation age in planted forests in Yen Bai province. The section starts with the discussion of criticisms towards direct payments. Some problems regarding the design of the payment schemes are raised. Possible solutions for these problems are also introduced.

Direct payments are blamed for raising ethical issues, eroding culture-rooted conservation values, and creating unemployment among other things. These criticisms towards direct payments, however, may be true for natural forests, but not for planted forests since local people still have access and can exploit the resources of the latter. Intuitively, after the initial payment rounds, when the payments stop, rotation ages may still be lengthened. This is because the farmers may be better-off than they currently are, and thus, can delay their harvest to get higher profit from large sized timber (beyond 10 years). In addition, by that time, forest owners may have established their forests to accommodate a sustainable harvest with a 10-year rotation length and are familiar with the market for large sized timber. This will help them to get a regular income to meet their daily basic needs.

There are some problems regarding the design of the payment schemes. This analysis made an assumption that payment is paid per hectare and purely based on the stand age. However, stand density (the number of trees per ha) also needs to be considered in a payment scheme[16], otherwise it will be problematic. If, for example, the payments were based on a stand of mature trees in an area, a problem would exist if stands with significantly greater amount of mature trees (high density) were eligible for the same payment as the ones with significantly fewer mature trees (low density). If so, forest farmers may cut a large proportion of their forests to sell and only keep a small number of mature trees to be eligible for receiving payments. As a result, the government still has to pay the money for enhancing biodiversity, while biodiversity in planted forests is not actually improved. A solution would be to employ a standard density for stand aged beyond 10 years (MARD, 2003) for determining this conditional payment.

Another problematic issue is whether the payments should be paid annually or at once at the end of the rotation (after 10 years). Currently, the Government makes a one-off payment to the forest owners who possess forests aged beyond 10 years, and either belong to minority groups or are based in remote areas. In contrast, this study suggests that the annual payments should be adopted because it would help poor people and gets support from forest owners. As discussed in section 4.2.4, at the chosen discount rate for the study, the carbon rotations for both payment schemes are identical, and the upfront payment might affect the willingness to join the carbon project of 51.7% households. The annual payment scheme for carbon sequestration service would be a more effective incentive than an upfront payment scheme.

The last area of contention relates to how much the government should pay to the forest owners. As reported earlier, for an annual payment, 93.4% of forest owners would delay their harvest if they were financially supported by the Government with an average amount of 5.5 m. VND per ha for each additional year (beyond 5 years). For a lump sum payment, forest owners would request an average amount of 21.4 m. VND per ha per rotation for them to delay their harvests until age 11 years on average. These two levels of payment are more than ten times higher

[16] This research uses 2189 trees per ha as stand density in the carbon sequestration function for households.

than the level of payment that is currently offered by the Government, 2 million VND/ha/10 years (Vietnamese Government, 2007a). However, compared with the optimal payment level reported in section 4.5.1 (approximately 6 million VND/ha/10 years), the levels of payment expected by forest owners are only three times higher. Nevertheless, it must be stressed that the optimal private rotation age (8 years) is longer than the actual rotation age (5 years). This might explain why the optimal payment level to lengthen rotation age is below the payment levels expected by the forest owners.

Additionally, lengthening rotation ages will reduce employment in a given period. This is because increasing rotation lengths leads to a larger area of mature forests, and conversely, a smaller area of young forests. As mature forests require less nutrition and tending, this, in turn, demands less labour. In this situation, ICDPs projects, such as butterfly and bird farming, ecotourism, and the cultivation of non-timber products could be a resort to create employment and improve the standard of living of forest owners and the local community.

CHAPTER FIVE.
SUMMARY AND CONCLUSIONS

5.1 INTRODUCTION

This final chapter provides a summary and conclusions of the thesis. Section 5.2 briefly states the problem and research questions. The major problem is the urgent need to incorporate the benefits of carbon sequestration and biodiversity maintenance into planted forest management. The research seeks to answer the optimal rotation age of planted forest when these benefits are taken into account. Methodology used and the major findings are also summarized in this section.

Section 5.3 recommends policy implications for the government of Vietnam to enhance carbon sequestration and biodiversity conservation in planted forests. This section also identifies limitations with regard to the methodology. Suggestions for some areas of further research are provided.

5.2 SUMMARY OF THE STUDY

5.2.1 Overview of the problem

Climate change and biodiversity loss are among the biggest challenges facing our generation. Using forests as a way of storing carbon to mitigate climate change is highly recommended since it is cheap (Sohngen, 2009; UNFCCC, 2009). Furthermore, biodiversity loss can be reduced significantly if strong actions at international, national and local levels to develop adaptive management strategies are taken urgently and appropriately (Leadley, et al., 2010). Again, forests -one of the most biologically rich terrestrial systems - can help to protect biodiversity via changes in forest management practices. In addition to timber production, other forest functions and services, such as recreation, biological diversity, and the mitigation of climate change, are increasingly recognized as integral components of sustainable forest management (CBD, 2002).

In Yen Bai province, Vietnam, most of the fast-growing tree species in productive planted forests are cut at the age of 5 year (Nguyen, et al., 2006). This cutting age is less than the optimal harvesting age that takes into account both timber production and carbon sequestration (Diaz-Balteiro & Rodriguez, 2006; van Kooten, et al., 1995). Moreover, the majority of forest farmers apply a clear-cut practice (Bui & Hong, 2006) that destroys habitat and causes serious loss of biodiversity (Pawson, et al., 2006). Since the area of planted forests will continue to expand in the next few years (Vietnamese Government, 2007a), there is an urgent need to adopt an optimal management strategy for planted forests in order to enhance carbon uptake and biodiversity conservation.

5.2.2 Purpose statement

This research has studied optimal forest harvesting strategies when carbon sequestration benefits and biodiversity conservation are included for *Eucalyptus urophylla* in Yen Bai province, Vietnam. In particular, the research has identified the optimal rotation age and its associated NPV from both a private and societal perspective. The optimal management strategy has been compared to the actual management practice applied in Yen Bai province, Vietnam to identify the gap. To reduce this gap, a suitable policy tool has been examined in order to encourage carbon sequestration and biodiversity protection in planted forests.

5.2.3 Review of the methodology

The Faustmann model was applied to find the optimal rotation age and the net present value for planted forest at stand level. This model was extended to include carbon sequestration and biodiversity conservation and to incorporate multi-stands and spatial arrangements among forest stand in order to analyse the optimal strategy at the forest level. The model was solved using direct search algorithms (a numerical method), which were coded in GAMS.

The model data were collected from both primary and secondary sources for planted forests in Vietnam. The primary data, including demographic information, timber production, forest management strategies, payment for carbon sequestration, and biodiversity conservation attitudes, were obtained via a survey (face-to-face interviews) in Yen Bai, Vietnam. The secondary data include timber growth, carbon uptake, and bird abundance for Vietnam planted forests.

To recommend a policy tool for enhancing biodiversity, the research included a review of the literature on public forest policies and analysed the socio-economic context in Vietnam. The results from the survey (demographic data, payment methods and conservation attitudes) and from the optimization models (the optimal rotation age and the optimal level of direct payments) contributed to the development of the policy tool.

5.2.4 Major findings

A survey of actual forest harvesting strategies shows that the tree cutting age is 5 years for households and 7 years for enterprises. However, the Faustmann rotation age of *Eucalyptus urophylla* is 9 years for both households and enterprises. The Faustmann rotation age of *Acacia mangium* is 11 years for both types of ownership. When carbon uptake has a price, the optimal rotation age is slightly shorter and the net present value is higher. The Faustmann *Acacia mangium* rotation age with carbon for enterprises (i.e. 10 years) is longer than that for households (i.e. 9 years). The NPV for enterprises is at least five times higher than that for households. For example, the Faustmann NPV of *Eucalyptus urophylla* is 7 and 45 millions VND per ha for households and enterprises, respectively.

Taking into account the spatial arrangements of forest stands has little impact on the optimal rotation age, however it does improve the net present value (13.01 million VND per ha on average). Nevertheless, both the timber and carbon ages are well-above the actual rotation age. Thus, there is an opportunity for policy intervention to increase the actual rotation age to achieve a more desirable harvesting pattern both from a private and societal point of view.

The optimal rotation age decreases with an increase in the carbon price, the planting subsidy level, the timber price, and the discount rate. The optimal rotation age is not sensitive to changes in economies of scale in planting and carbon payment schemes. However, these changes do have an impact on the NPV.

The results show that the inclusion of the MVP into the optimization model induces a longer rotation age compared to the timber and carbon rotation ages for *Eucalyptus urophylla*. The biodiversity rotation age (when the MVP is 50) is between 10 and 11 years. The average NPV is 11.46 million VND per ha.

A sensitivity analysis shows that the optimal rotation age increases with a rise in the MVP. The NPV decreases with an increase in the MVP. The optimal rotation age does not always decrease with a rise in the discount rate, however, the NPV is significantly reduced as the discount rate increases. An increase in the carbon price or in the timber price has no effect on the biodiversity rotation age at the chosen discount rate (8%), but significantly increases the NPV.

Given the poverty of forest owners and the direct effect on biodiversity of direct payments, it would be appropriate to pay forest owners for lengthening rotation ages. The study finds that the optimal payment level to bring a private rotation age to a social rotation age is 0.54 million VND/ha/year.

5.3 CONCLUSIONS

5.3.1 Policy implications

The policy implications of this study are outlined below. Firstly, the payment for carbon sequestration services of planted forests in Vietnam is a feasible policy (i.e. the Government can pay household forest owners for the carbon sequestration services provided by their planted forests). This is in line with present Government policies. The Vietnamese Government ratified the Kyoto Protocol and has already implemented some trial projects to pay for environmental services including carbon sequestration. In addition, the study's results show that the net present value is higher when carbon sequestration has value. That is, the forest households will be better off if the carbon sequestration service provided by their forests is paid for. The majority of forest households have agreed to engage in a carbon pooling project if it is proposed. Nearly half of the respondents recommended that a contract for the carbon pooling project between the investors and households needs to be adopted. The respondents expressed their concerns about obstacles for implementing the carbon pooling project, such as catastrophic risks and price uncertainty, the possibility of bankruptcy of the investor, and earlier harvesting by poor households. Thus, to implement the carbon pooling project, both a contract between the investor and the household, and a mechanism to insure households from risks are recommended.

The second policy implication is that merging small forest stands belonging to one household or several forest households, should be encouraged. It is commonly accepted that planted forests that are managed at a larger scale will be more profitable. This study shows that when managing forests at forest level (that is at least two stands) instead of stand level (that is only one stand), the NPV per ha per rotation is higher. According to survey results, at least 61% of households possess forest wood lots that are in different geographical places. Hence, if these wood lots are pooled together (through the exchange of wood lots between households), with the potential economies of scale, the NPV will be higher. Another way to pool wood lots together is by merging adjacent pieces of land belonging to different households. The Vietnamese Government currently encourages the process of merging agricultural lands, and thus, pooling forest lands could be the next step.

Another policy implication is that mechanisms to reduce uncertainty in forest plantations should be encouraged. The actual rotation ages for household planted forests are too short compared to the optimal rotation ages. This is because there is significant uncertainty in timber prices and harvest volumes as well the poverty of the households. Hence, government policies to encourage the development of forest insurance can help to increase the actual rotation ages. Another policy to lengthen the rotation ages can be to encourage investment in wood-processing enterprises in planted forests, which guarantees the demand side for timber.

The final policy implication is that there is a wide range of policy tools that can be used to enhance biodiversity in planted forests. However, the selection of a policy tool depends both on the services themselves and the local conditions. Given the specific condition of the forestry sector in Vietnam, direct payments is the appropriate policy tool to enhance biodiversity in planted forests. This result is supported by the findings from the household survey, the literature review, and the analysis of optimal payment for promoting biodiversity. The study also suggests that the payments should also be made annually to forest owners. The level of payment expected by household forest owners as well as the optimal level resulting from the optimization model is significantly higher than the current level applied by the Government. The study, therefore, suggests that the Government should increase the level of direct payment to induce households to lengthen rotation age for biodiversity conservation.

5.3.2 Limitations

The biodiversity optimization model has several limitations regarding the biodiversity function. As described in equation (18), the number of birds depends only on the age of forest stands, the older the stands the higher the number of birds. This limitation of the model has two aspects. Firstly, the number of birds may also be affected by other biological variables, such as forest plant density and diversity, type of dominant tree species, and disturbance intensity. However, the inclusion of other biological parameters makes the models more complicated, and they are not important in the decision-making process (i.e. selecting appropriate policy tools to enhance biodiversity). Secondly, as the age of a forest stand increases, the number of birds will increase indefinitely. Under this circumstance, incorporating other biological variables will keep the number of birds within a given range. However, as the model's constraint is to achieve a minimum number of birds, a maximum number does not affect the performance of the model.

Another weakness of the biodiversity optimization model in this study is that it does not consider corridors in fragmented areas in planted forests so that birds can move across forest stands. Landscape fragmentation - gaps created by clear cutting forest stands - could affect the movement of vertebrate species across forest stands. However, as most birds are good fliers and their home range sizes range from 4 to 40 ha, their travelling ability will not be affected if the clear-cut sizes are relatively small. The optimization model is applied to private planted forests in Yen Bai, Vietnam, which are only 3.95 ha on average (see section 4.2.1). Thus, gaps created by clear-cut areas that are not included in the model will not affect bird travelling and hence, the model's results.

5.3.3 Recommendation for further research

Trees sequester carbon when they grow and release carbon after harvest. The amount of carbon emitted depends on the types of timber products. For example, almost all the carbon is released immediately after harvest if timber is burnt as fuel wood. However, it might take a hundred years for timber which is used as furniture to emit the whole amount of carbon. This study, however, follows the literature that treats the forest as carbon neutral over its life cycle. That is the amount of carbon sequestered equals the carbon emissions after harvest. For future work, it might be interesting if the different rates of carbon released after harvest are considered.

The study is based on the assumption that timber price is constant. If a varying timber price is used, the timber rotation age will be closer to the biodiversity rotation age (15 years) as shown in section 4.3.6. The NPV associated with the biodiversity rotation age will also be similar to that of the timber rotation. The government payment for biodiversity conservation will encourage forest owners to adopt a rotation age closer to the economic rotation age for planted forests.

This study does not address environmental benefits other than carbon sequestration and biodiversity preservation, such as water supply and quality benefits; and other forest management practices, like uneven-aged stands and thinning. Consideration of these benefits and practices in a forest level model would be interesting, and a fruitful area for further research.

Since there is a big gap between the payment levels offered by the government and the ones expected by forest owners, further research should help to identify an effective compromise in payment levels. Also, research on how to set up ICDPs projects, such as butterfly and bird farming, ecotourism, and the cultivation of non-timber products, in planted forests should be conducted. This would help to create employment that will be lost as a result of lengthening rotation ages.

APPENDICES

APPENDIX A Annual increment of timber growth and carbon uptake

Table The first derivative functions of timber growth and of carbon sequestration for *Eucalyptus urophylla* and *Acacia mangium*

Age of timber (x)	Annual increment of timber / carbon (q)			
	(1)	**(2)**	**(3)**	**(4)**
1	37.57	5.8735	27.46	4.9104
2	34.81	5.7315	26.86	4.8494
3	32.05	5.5895	26.26	4.7884
4	29.29	5.4475	25.66	4.7274
5	26.53	5.3055	25.06	4.6664
6	23.77	5.1635	24.46	4.6054
7	21.01	5.0215	23.86	4.5444
8	18.25	4.8795	23.26	4.4834
9	15.49	4.7375	22.66	4.4224
10	12.73	4.5955	22.06	4.3614
11	9.97	4.4535	21.46	4.3004
12	7.21	4.3115	20.86	4.2394
13	4.45	4.1695	20.26	4.1784
14	1.69	4.0275	19.66	4.1174
15	-1.07	3.8855	19.06	4.0564
16	-3.83	3.7435	18.46	3.9954
17	-6.59	3.6015	17.86	3.9344
18	-9.35	3.4595	17.26	3.8734
19	-12.11	3.3175	16.66	3.8124
20	-14.87	3.1755	16.06	3.7514
21	-17.63	3.0335	15.46	3.6904
22	-20.39	2.8915	14.86	3.6294
23	-23.15	2.7495	14.26	3.5684
24	-25.91	2.6075	13.66	3.5074
25	-28.67	2.4655	13.06	3.4464
26	-31.43	2.3235	12.46	3.3854
27	-34.19	2.1815	11.86	3.3244
28	-36.95	2.0395	11.26	3.2634

29	-39.71	1.8975	10.66	3.2024
30	-42.47	1.7555	10.06	3.1414
31	-45.23	1.6135	9.46	3.0804
32	-47.99	1.4715	8.86	3.0194
33	-50.75	1.3295	8.26	2.9584
34	-53.51	1.1875	7.66	2.8974
35	-56.27	1.0455	7.06	2.8364
36	-59.03	0.9035	6.46	2.7754
37	-61.79	0.7615	5.86	2.7144
38	-64.55	0.6195	5.26	2.6534
39	-67.31	0.4775	4.66	2.5924
40	-70.07	0.3355	4.06	2.5314
41	-72.83	0.1935	3.46	2.4704
42	-75.59	0.0515	2.86	2.4094
43	-78.35	-0.0905	2.26	2.3484
44	-81.11	-0.2325	1.66	2.2874
45	-83.87	-0.3745	1.06	2.2264
46	-86.63	-0.5165	0.46	2.1654
47	-89.39	-0.6585	-0.14	2.1044
48	-92.15	-0.8005	-0.74	2.0434
49	-94.91	-0.9425	-1.34	1.9824
50	-97.67	-1.0845	-1.94	1.9214

Note: (1) Rate of timber growth (m^3 per year) for *Eucalyptus urophylla*: q(x)=-2.76x + 40.33

(2) Rate of carbon sequestration (tonne per year) for *Eucalyptus urophylla*: q(x)=-0.142x + 6.0155

(3) Rate of timber growth (m^3 per year) for *Acacia mangium*: q(x)=-0.6x + 28.06

(4) Rate of carbon sequestration (tonne per year) for *Acacia mangium*: q(x)=-0.061x + 4.9714

APPENDIX B Questionnaires

Enterprise/management board Questionnaire Code B□□□

District:…………….Commune:……………….Enterprise/management board:…

Interviewee:..

Interviewer:..

Date of interview:...

I. Production situation

1. Number of managers and office staff (people):.......................................
2. Number of workers (people):...

Type of land	Area (ha)	Land ownership	Land use duration (year)	Land use tax (thousand VND/ha/year)
Plantation production forests	3.	4. 1.Allocating 2.Contracting out 3. Leasing	5.	6.
Natural production forests	7.	8. 1.Allocating 2.Contracting out 3. Leasing	9.	10.
Others	11.	12. 1.Allocating 2.Contracting out 3. Leasing	13.	14.

15. Total number of compartments in plantation production forests:…............

Compartment	1	2	3	4	
Area (ha)	16.	17.	18.	19.	20.
Tree species	21. 1. Euc. urophylla 2. Aca. mangium 3. Others	22. 1. Euc. urophylla 2. Aca. mangium 3. Others	23. 1. Euc. urophylla 2. Aca. mangium 3. Others	24. 1. Euc. urophylla 2. Aca. mangium 3. Others	25. 1. Euc. urophylla 2. Aca. mangium 3. Others
Tree age (year)	26.	27.	28.	29.	30.
Density (trees/ha)	31.	32.	33.	34.	35.
Estimated volume (m^3/ha)	36.	37.	38.	39.	40.
Estimated harvesting year (solar calendar)	41.	42.	43.	44.	45.

Estimated forest value (land and stumpage prices) million VND	46.	47.	48.	49.	50.
Adjacent compartments	51.	52.	53.	54.	55.
Name of understorey species	56.	57.	58.	59.	60.

61. Site class of plantation production forests: □ I □ II □ III □ IV
62. Distance from plantation production forests to main roads (km):………..
63. Distance from natural production forests to main roads (km):……… …..
64. Harvesting systems applied for plantation production forests:

1. Clear logging 2. Selection logging
3. Group logging 4. Others

65. Harvesting systems applied for natural production forests:

1. Clear logging 2. Selection logging
3. Group logging 4. Others

II. Production costs

Cost	Amount of money (million VND/year)
66. Natural production forests	
67. Other costs	
68. Cost for plantation production forests	
69. Materials in forest establishment stage	
70. Labours in forest establishment stage	
71. General cost	
72. Forest tending in year 1	
73. Forest tending in year 2	

74. Forest tending in year 3	
75. Forest protection in years 4 -6	
76. Forest protection in years 7 -10	
77. Forest protection in years >10	
78. Forest harvesting in years 4 -6	
79. Forest harvesting in years 7 -10	
80. Forest harvesting in years >10	
81. Transportation (**million** VND/year or m^3)	
82. Bank loan payments	
83. Other costs	
84. Self-support capital for plantation production forests	
85. Loan capital for plantation production forests	

Support from the state for plantation production forests:

86. Capital:..........………………..

87. Seeds:……………...

88. Technical support:........………..

89. Others:...…… …...

III. Consumption information

90. Income from natural production forests in 2007 (**million** VND): ………....

91. Income from plantation production forests in 2007 (**million** VND): ……..

Tree species	Harvesting area (ha)	Harvesting volume (m^3)	Harvesting age (year)	Harvesting cost (million VND)	Selling price (thousand VND/m^3)	Selling place
92. 1. Euc. urophylla 2. Aca. mangium 3. Others	93.	94.	95.	96.	97.	98. 0. Stumpage price 1. Landing 1 2. Direct delivery
99. 1. Euc. urophylla 2. Aca. mangium 3. Others	100.	101.	102.	103.	104.	105. 0. Stumpage price 1. Landing 1 2. Direct delivery
106. 1. Euc. urophylla 2. Aca. mangium 3. Others	107.	108.	109.	110.	111.	112. 0. Stumpage price 1. Landing 1 2. Direct delivery

113. Income from other sources in 2007 (**<u>million</u>** VND): ……………...............

V. Management strategies

Do you decide to harvest forests and to make management cycle depending on:

114. Forest age
115. Timber price
116. Enterprise's economic status
117. Banking interest rate
118. Government's policies
119. Decisions of other enterprises in your province
120. Self-support capital
121. Other reasons..

Do you decide to plant main tree species depending on:

122. Government's policies
123. Self-support capital
124. Enterprise's economic status
125. Profit
126. Decisions of other enterprises in your province
127. Other reasons...

Suppose you are supported by the Government to delay the harvesting of forests, how much would you like to receive (VND/ha/year) to delay the harvesting for:

128. 1 year…………..........
129. 2 years……………........
130. 3 years……………….....
131. 4-6 years……….......
132. > 6 years…..................

133. What factors do your take into consideration in answering the above question?

....
....
....

134. Beside providing timber, plantation forests are environmentally valuable, specifically carbon sequestration. Many organizations, companies and individuals are willing to pay money for forest growers to keep their forests for carbon

sequestration. Suppose you are received money from keeping your forests for carbon sequestration, what payment methods would you like to choose:

1. Annual payment (you will be given annual carbon service payments from forest canopy closure or from year 4 afterwards until forest harvesting).

2. Full payment during forest establishment and you have to sign a pledge to keep your forests until it reaches a certain age.

135. How much would be reasonable (VND/ha/year): …………………..…….
136. and until which years can you pledge to keep your forests: ………..….

Suppose an investor wants to establish forests in an area with the participation of households, beside income from timber selling you will be given some payments from keeping your forests for carbon sequestration. Are you willing to unite with other households to plant forests for carbon service support as required by the project (for example: same species, time, technique)?

137. Yes. Please give your reasons:………………………............................
…………………………………………………………………………………
138. No. Please give your reasons:…………………………………………..…
…………………………………………………………………………………
…………………………………………………………………………………
139. Unknown. Please give your reasons:…………….………..…………
…………………………………………………………………………………
140. Necessary procedures to unite among enterprises:……………
…………………………………………………………………………………
141. Obstacles to be emerged:………………………… …………………..…
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………
…………………………………………………………………………………

Are there wildings and understorey cultivated crops in your production plantation forests?

142. Yes
143. No

If Yes, under which of the following values do those plant species belong to:

144. Marketable
145. Soil and water protected
146. Landscape valuable

147. Seed reserved

148. Nonvaluable

If your enterprise is supported, are you willing to grow a variety of plant species to improve the above-mentioned values?

149. Yes. Please give your reasons:………… ………….………………. ……
…………………………………………………………………..……………

150. No. Please give your reasons:………………………..………………
……………………………………………………………………….…………

151. Unknown. Please give your reasons:……………… ………….… ………..
…………………………………………………………………………………

152. Information on forest status maps (technical office), summary reports of management activities, management direction, management strategy and norms on production costs applied for forests of the enterprise.

153. Information on costs and consumption.

Household Questionnaire **Code A□□□**

District:…………Commune:……....….Village…………………House No.:.......

Interviewee:...

Interviewer:..

Date of interview:..

I. General information

1. Age:...........................
2. Gender: 0. Male 1. Female
3. Ethnic group: 0. Kinh 1. Others
4. Educational level: ..../12
5. Number of household's people: ....
6. Number of family's labours working at home:.............................
7. Number of family's labours working for others:....................................
8. Number of hired labours:...
9. Household level: 1. Well-off 2. Poor 3. Average

II. Production situations

Type of land	**Area (ha)**	**Land ownership**	**Land use duration (year)**	**Land use tax (<u>thousand</u> VND/ha/year)**
Plantation production forests	10.	11. 1. Allocating 2.Contracting out 3. Leasing	12.	13.
Natural production forests	14.	15. 1. Allocating 2. Contracting out 3. Leasing	16.	17.
Restored and protected forests	18.	19. 1. Allocating 2. Contracting out 3. Leasing	20.	21.
Agricultural land	22.	23. 1. Allocating 2. Contracting out 3. Leasing	24.	25.

Others	26.	27. 1. Allocating 2. Contracting out 3. Leasing	28.	29.

30. Distance from plantation production forests to main roads (km):.................

31. Harvesting systems: 1. Clear logging 2. Selection logging
3. Group logging 4. Others

32. Total of patches in plantation production forests:……........................

Patch (pure and even age)	**1**	**2**	**3**	**4**	**5**
Area (ha)	33.	34.	35.	36.	37.
Tree species	38. . *Eucalyptus* *rophylla* . *Acacia* *angium* . Others	39. . *Eucalyptus* *rophylla* . *Acacia* *angium* . Others	40. . *Eucalyptus* *rophylla* . *Acacia mangium* . Others	41. . *Eucalyptus* *rophylla* . *Acacia mangium* . Others	42. . *Eucalyptus* *rophylla* . *Acacia* *angium* . Others
Tree age (year)	43.	44.	45.	46.	47.
Density (trees/ha)	48.	49.	50.	51.	52.
Estimated volume (m^3/ha)	53.	54.	55.	56.	57.
Estimated harvesting year (solar calendar)	58.	59.	60.	61.	62.
Estimated forest value (land and stumpage prices in 2007) million VND	63.	64.	65.	66.	67.
Adjacent patches	68.	69.	70.	71.	72.
Name of understorey species	73.	74.	75.	76.	77.

Are there wildings and understorey cultivated crops in your production plantation forests?

78. Yes

79. No

If Yes, under which of the following values do those plant species belong to

80. Marketable

81. Soil and water protected

82. Landscape valuable

83. Seed reserved

84. Nonvaluable

……………………………………………………………………………………………

If your family is supported, are you willing to grow a variety of plant species to improve the above-mentioned values?

85. Yes. Please give your reasons:…………………………………

………………………………………………………………….………

……………………………………………………………………………….

86. No. Please give your reasons:……………………. ………………

……………………………………………………………………………

87. Unknown. Please give your reasons…………….. ……………

…………………………………………………………………….…..

III. Production costs (based on forest area of the family)

Cost	Amount of money (million VND/year)
88. Natural production forests	
89. Restored and protected forests	
90. Agricultural production	
91. Other costs	

Cost for plantation production forests	**92. Eucalyptus urophylla (1)**	**93. Acacia mangium (2)**	**94. Other species (3)**
Materials in forest establishment stage - Fertilizers - Seedlings	**95.**	**96.**	**97.**
Labours in forest establishment stage	**98.**	**99.**	**100.**
Forest tending in year 1	**101.**	**102.**	**103.**
Forest tending in year 2	**104.**	**105.**	**106.**
Forest tending in year 3	**107.**	**108.**	**109.**
Forest protection in years 4 - 6	**110.**	**111.**	**112.**
Forest protection in years 7 - 10	**113.**	**114.**	**115.**
Forest protection in years > 10	**116.**	**117.**	**118.**
Forest harvesting in years 4 - 6	**119.**	**120.**	**121.**

- Thinning - Harvesting			
Forest harvesting in years 7 - 10 - Thinning - Harvesting	**122.**	**123.**	**124.**
Forest harvesting in years > 10 - Thinning - Harvesting	**125.**	**126.**	**127.**
Transportation - Thinning - Harvesting	**128.** **(million** /ND/year or m^3)	129.	130.
Bank loan payments	**131.**	**132.**	**133.**
Other costs - Logging - Loading and pulling	**134.**	**135.**	**136.**
Self-support capital for plantation production forests in 2007	**137.**	**138.**	**139.**

Loan capital for plantation production forests in 2007	**140.**	**141.**	**142.**

Support from the state for plantation production forests:

143. Capital: ……………..

144. Seeds and seedlings: ……………..

145. Technical support: ……………..

146. Others:

……………..

…………………………………………………………………..…………………

…………………………………………………………………………...………

147. How much less have you spent for your production forest in comparison with the norm of the forest enterprise? (million VND/ha) ………………….

……………………………………………………………………………………

...……………………………………………………………………………………

IV. Consumption information

148. Income from plantation production forests in 2007 (**million** VND): ……

Tree species	Types of product	Harvesting area (ha)	Harvesting volume (m^3)	Harvesting age (year)	Harvesting cost (million VND)	Selling price (thousand VND/m^3)	Selling place
149. 1. Eucalyptus urophylla 2. Acacia mangium 3. Others	150. . Thinning . Harvesting	151.	152.	153.	154.	155.	156. 0. Stumpage price 1. Landing 1 2. Direct delivery
157. 1. Eucalyptus urophylla 2. Acacia mangium	158. . Thinning . Harvesting	159.	160.	161.	162.	163.	164. 0. Stumpage price

3. Others							1. Landing 1 2. Direct delivery
165. 1. Eucalyptus urophylla 2. Acacia mangium 3. Others	166. . Thinning . Harvesting	167.	168.	169.	170.	171.	172. 0. Stumpage price 1. Landing 1 2. Direct delivery
173. 1. Eucalyptus urophylla 2. Acacia mangium 3. Others	174. . Thinning . Harvesting	175.	176.	177.	178.	179.	180. 0. Stumpage price 1. Landing 1 2. Direct delivery
181. 1. Eucalyptus urophylla 2. Acacia mangium 3. Others	182. . Thinning . Harvesting	183.	184.	185.	186.	187.	188. 0. Stumpage price 1. Landing 1 2. Direct delivery
189. 1. Eucalyptus urophylla 2. Acacia mangium 3. Others	190. . Thinning . Harvesting	191.	192.	193.	194.	195.	196. 0. Stumpage price 1. Landing 1 2. Direct delivery

197. Income from natural production forests in 2007 (**million** VND): …………

Type of product	Volume	Selling price	Selling place
198.	199.	200.	201.
202.	203.	204.	205.
206.	207.	208.	209.

210. Income from restored and protected forests in 2007 (**million** VND): …..

Type of product	Volume	Selling price	Selling place
211.	212.	213.	214.
215.	216.	217.	218.
219.	220.	221.	222.

223. Income from agriculture in 2007 (**million** VND): ……………….........

Type of product	Volume	Selling price	Selling place
224.	225.	226.	227.

228.	229.	230.	231.
232.	233.	234.	235.

236. Income from other sources in 2007 (**million** VND): …………………..........

Type of product	Volume	Selling price	Selling place
237.	238.	239.	240.
241.	242.	243.	244.
245.	246.	247.	248.

…………..

……………………………………………………………………………………

……………………………………………………………………………………

V. Management strategies

Do you decide to harvest forests and to make management cycle depending on (in priority from 1-3):

249. ☐ Forest age
250. ☐ Timber price
251. ☐ Family's economic status
252. ☐ Banking interest rate
253. ☐ Government's policies
254. ☐ Decisions of adjacent households
255. ☐ Self-support capital
256. ☐ Other reasons...

Do you decide to plant main tree species depending on (in priority from 1-3):

257. ☐ Government's policies
258. ☐ Self-support capital
259. ☐ Family's economic status
260. ☐ Profit
261. ☐ Decisions of adjacent households
262. ☐ Other reasons..

If you are supported by the Government to delay the harvesting of forests, how much would you like to receive (VND/ha/year) to delay the harvesting for:

263. 1 year……………………… ....

264. 2 years………...............................

265. 3 years……………………………..

266. 4-6 years………...............................

267. > 6 years…......................................

268. What factors do your take into consideration in answering the above question?

....

....

....

269. Beside providing timber, plantation forests are environmentally valuable, specifically carbon sequestration. Many organizations, companies and individuals are willing to pay money for forest growers to keep their forests for carbon sequestration. Suppose you are received money from keeping your forests for carbon sequestration, what payment methods would you like to choose:

1. Annual payment (you will be given annual carbon service payments from forest canopy closure or from year 4 afterwards until forest harvesting).

2. Full payment during forest establishment and you have to sign a pledge to keep your forests until it reaches a certain age.

270. How much would be reasonable (VND/ha/year): ………………………………………………………………………………………

………………………………………………………………………………………

271. and until which years can you pledge to keep your forests: ……………………..………

Suppose an investor wants to establish forests in an area with the participation of households, beside income from timber selling you will be given some payments from keeping your forests for carbon sequestration. Are you willing to unite with other households to plant forests for carbon service support as required by the project (for example: same species, time, technique)?

272. Yes. Please give your reasons:………………………
……………………………………………………………………..
……………………………………………………………………..

273. No. Please give your reasons:…….……………………………....
……………………………………………………………………..
……………………………………………………………………..

274. Unknown. Please give your reasons :………………… ………
………………………………………………………………………
………………………………………………………………………

275. Necessary procedures to unite among households:……………
………………………………………………………………………
………………………………………………………………………

276. Obstacles to be emerged:…………………… ……………………..
………………………………………………………………………
………………………………………………………………………
………………………………………………………………………

277. Can I copy (redraw) your forest status map/green book?

APPENDIX C GAMS Coding

GAMS coding for the carbon sequestration model at stand level

```
scalar i  j  k Z ot;
set o    Optimal value of different discount rate /1*11/;
set      Name/Hh-Eu-carbon-sgl-50y,r,T,NPV/;

parameter
        exr(o)          Discount rate
        exV(o)          NPV of stand
        exAV(o)         Age of stand
        t               Age
        ra              Rotation age
        r               Discount rate
        b               Discount factor
        bf              Discount factor used for planting cost in the beginning of
                        rotation

        Te              Planning period-Time end
        Tra             Maximum value of rotation (years)

        gr              Volume of timber (scalar)  (m3)
        grc             Amount of carbon sequestered (ton)
        dsval           Discounted value of timber

        p               Price of timber per unit volume-million VND per m3
        pc              Price of carbon-million VND per ton
        pl              Planting cost-million VND per ha

        maxV            Highest discounted value
        maxAV           Optimal Rotation Age associated with the highest
                        discounted value

        m               Technical variable
        s               Technical variable
        ta              Additional years after rotation
        ex              Technical variable
        dex             Technical variable;

            Tra=50;
            Te=50;

            r = 0;
            dex=0;


FOR (Z=1 TO 10,
```

```
    r = r+0.01;
    dex=dex+1;
    ra=0;

    p = 0.37;
    pc=0.051;
    pl = 6.85;
    maxV = 0;


FOR (j=1 TO Tra,
        ra = ra+1;
        gr = (-1.3708*ra*ra + 40.326*ra - 94.073)/3;
        grc= -0.071*ra*ra + 6.0155*ra + 11.567;
        *{J is rotation age, i is planning horizon}

        dsval = 0;
        bf=1;
        s = 0;
         t =0;

                FOR (i=1 TO Te,
                        t = t+1;
                        b = (1+r)**(t-1);
                        m = Te/ra;

                        for (k = 1 to m,
                                if (t = ra*k,
                                        s = s+1;
                                        dsval = dsval - pl/bf + gr*p/b +
                                        (grc*pc)/b;
                                        bf=b*(1+r);
                                );
                        );
                        *{END k}
                );
                *{END i}

        If (ra*s < Te,
                 ta = Te - (s*ra);
                gr = (-1.3708*ta*ta + 40.326*ta - 94.073)/3;
                grc= -0.071*ta*ta + 6.0155*ta + 11.567;
                dsval = dsval - pl/bf + gr*p/b + (grc*pc)/b;
        );

        If ( dsval>maxV,
                maxV = dsval; maxAV = ra);
```

```
        );
        *{END j}

      ex=0;
      Loop (o,
                 ex=ex+1;
                 if (ex=dex,
                         exr(o)=r;
                         exv(o)=maxv;
                         exav(o)=maxav;
                  );
      );

);
*{END Z}

DISPLAY exr, exv, exav, dex;
EXECUTE_unload "EEP12-125-090721.gdx" exr, exv, exav, name
EXECUTE 'gdxxrw.exe EEP12-125-090721.gdx par=exv rdim=1 rng=d2:d11,
par=exav rdim=1 rng=c2:c11, par=exr rdim=1 rng=b2:b11, set=name rng=b1:e1 '
```

GAMS coding for the biodiversity optimization model at forest level

```
Scalar   i,j,z;

Set    s     Number of stands (adjust n) WARNING/1*5/
       sr    Row-Number of cases forest /1*10/
       o     Discount rate set /1*100/
       SO      SENSITIVITY ANALYSIS /1*10/
       ;
Set    name1/Eu-Carbon-FR-NPV-ha-CV-50y/
       namer/r/
       nameT/T/
       nameV/NPV/
       namemvp/MVP/
       nameB/Birds/
       nameF/Butterflies/;

Parameter
       a0     Parameter of timber growth function
       b0     Parameter of timber growth function
       c0     Parameter of timber growth function

       Q      Volume of harvested timber=a*t^2+b*t+c
       Qc     Amount of carbon sequested of a stand (tons)

       n      Number of stands
```

Te	End time
Tra	Maximum rotation age
Te0	echnical variable to count years toward the end of planning horizon
Tmax	Optimal rotation age
U	The net present value
Umax	Technical variable
Tfa	Total forest area (size) - ha
T	Technical variable
s1	Technical variable
r	Discount rate
dex	Technical variable of discount rate
case	Technical variable
case0	Technical variable
ex	Technical variable
df	Time t to calculate discount factor
p	Price of timber per m3 (million VND)
pc	Price of carbon per ton (million VND)
k	Planting cost according to planted area
Cv	Power of planting cost according to planted area
bcv	Constant multiply with variable cost
lgc	Log cost (ln base e)
cl	Number of stand of Clear-cut area
cs	Size of clearcut area -ha
aof	Average age of forest at current year
Bio	Technical variable if MVP is achieved
MVP	Minimum viable population for both birds and butterflies
Sbt	Abundance of birds at every year
Sft	Abundance of butterflies at every year (individuals)
SbtT	Total abundance of birds over planning horizon
SftT	Total abundance of butterflies over planning horizon
SbtTmax	Max Total abundance of birds over planning horizon
SftTmax	Max Total abundance of butterflies over planning horizon;

Parameter

exr(o,so)	discount rate
exV(o,so)	NPV of stand
exAV(o,so)	Age of stand
exSbt(o,so)	Abundance of birds
exSft(o,so)	Abundance of butterflies;

PARAMETER MVPs(SO) SENSITYVITY ANALYSIS OF MPV /1 0, 2 45, 3 50, 4 60, 5 70, 6 80, 7 100, 8 150, 9 200, 10 250/;

n=5;
a0=-1.38;
b0=40.33;
c0=-94.07;

Te=50;
Tra=50;

p=0.37;
pc=0.051;
cv=0.98;
bcv=5.17;

MVP=50;

Table stb (sr,s) Area of forest cases

	1	2	3	4	5
1	3.1	2.9	1	0.8	0.8
2	3.1	2.9	1	0.8	0.8
3	1	0.3	0	0.3	0
4	1	0.3	0	0.3	0
5	3	1	1	0	0
6	3	1	1	0	0
7	2	0.5	1	0	0
8	2	0.5	1	0	0
9	1	1	0	0	0
10	1	1	0	0	0

Table xtb (sr,s) Initial Age of forest cases

	1	2	3	4	5
1	3	3	3	3	3
2	0	0	0	0	0
3	4	2	2	2	0
4	0	0	0	0	0
5	1	1	1	0	0
6	0	0	0	0	0
7	2	1	1	0	0
8	0	0	0	0	0
9	4	2	0	0	0
10	0	0	0	0	0

Parameter

x0(s)	Initial Age of stand
x(s)	Current age of stand
ssz(s)	Stand size

```
        d(s)      Decision to cut /1*5 0/
        cla(s)    Number of connected clear-cut Stands /1*5 0/
        cls(s)    Size of connected clear-cut area -ha/1*5 0/;

         case=-10;
         exr(o,so)=-1110;
         exV(o,so)=-1111;
         exAV(o,so)=-1112;
         exSbt(o,so)=-1113;
         exSft(o,so)=-1114;


case0=0;

LOOP (sr,
          x0(s)= xtb(sr,s);
          ssz(s)=stb(sr,s);
          case=case+10;
          *Calculate total forest size ha
          tfa=0;
          Loop (s,tfa=tfa+ssz(s));

          LOOP (so,
                    MVP=MVPs(so);
                    r=0;   dex=case;  case0=case0+1;
                     FOR (Z=1 TO 10,
                              r=r+0.01;  dex=dex+1;
                              T=0;  Umax=-999999999;
                              SbtTmax=-2222;     SftTmax=-2222; Tmax=-33;


                              *To calculate NPV for every rotation age ranges from 1 to
                    Tra
                              FOR (i = 1 to Tra,
                                        T=T+1;
                                        U=-exp(log(bcv)+cv*log(tfa));
                                        df=-1;
                                        x(s)=x0(s);
                                        Te0=0;
                                        Bio=1;
                                        SbtT=0;
                                        SftT=0;

                                        For (j=1 to Te,
                                                  d(s)=0;
                                                  Te0=Te0+1;
                                                  df=df+1;
```

```
*Calculate abundance of birds every year
 Sbt=0; Sft=0;
Loop (s,
        If ((x(s)>0 and ssz(s)>0),Sft=Sft+((-
        875.29)*log(x(s))+ 4978.8)*ssz(s);
        Sbt=Sbt+(22.215*exp(0.1421*x(s)))
        *ssz(s); );
        If (x(s)=0 and
        ssz(s)>0,Sbt=Sbt+22.22*ssz(s);
        Sft=Sft+4978.8*ssz(s));
);

SbtT=SbtT+Sbt/tfa;
SftT=SftT+Sft/tfa;
*Assign Desion to cut stand or not Dst, If end time, cut all stands
s1=0;
Loop (s,
        If ((x(s)>=T),
        d(s)=1; );
);
If (Te0=Te, d(s)=1);

*Find Number of Connected Clearcut Stands, Size of connected
clearcut and harvest volume of each clearcut cluster
cl=0;  cs=0;
cla(s)=0;   cls(s)=0;
s1=0;
Loop (s,
      s1=s1+1;
      If ((s1>1) and (s1<n),
            If ((d(s)=1) and (d(s+1)=1),
                  If (d(s-1)=0,cl=cl+2;  cs=cs+ssz(s)+ssz(s+1); );
                  If (d(s-1)=1,cl=cl+1; cs=cs+ssz(s+1); );
            );

            If (d(s)=1 and d(s+1)=0,
                  If (cl>0,cla(s)=cl; cls(s)=cs;);
                  If (cl=0,cla(s)=1; cls(s)=ssz(s););
                  cl=0;  cs=0;
            );
      );
      If ((s1=1),
            If (d(s)=1 and d(s+1)=1,
                 cl=cl+2; cs=cs+ssz(s)+ssz(s+1);
            );

            If (d(s)=1 and d(s+1)=0,
                  cla(s)=1;   cls(s)=ssz(s);
```

```
                    cl=0;  cs=0;
                );
            );
            If ((s1=n)and (d(s)=1),
                    If (cl>0,cla(s)=cl;cls(s)=cs;);
                    If (cl=0,cla(s)=1;cls(s)=ssz(s););
                    cl=0;  cs=0;
             );

        );
                *End finding clearcut connected stands

*Calculate Planting cost Next year-based on Harvested area

                k=0;
                Loop (s,
                        if (cls(s)>0,
                                k=k+exp(log(bcv)+cv*log(cls(s)));
                        );
                );
                *End planting cost

*Calculate Timber volume, add size of stand
        Q=0; Qc=0;
        Loop (s,
            If ((d(s)=1),
                Q=Q+(a0*x(s)*x(s)+b0*x(s)+c0)*ssz(s)/3; Qc=Qc + (-
                0.071*x(s)*x(s)+6.0155*x(s)+11.567)*ssz(s);
                if (x(s)>0, x(s)=-1;)
            );
        );

*End timber volume

*The Net present value
        If (Q<0,Q=0;);
        U=U + ((p*Q)/(power((1+r),df))) + ((pc*Qc)/(power((1+r),df)));
        if ((k<>0) and (Te0<Te), U=U-k/(power((1+r),(df+1))));
*End NPV

*Increase stand age
        x(s)=x(s)+1;

                );
                *END for J planning horizon


                *OPTIMAL STRATEGY
```

```
                    U=U/tfa;
                    Bio=1;
                    If ((SbtT/Te)<MVP, Bio=0);
                    If (U>=Umax and U>0 and bio=1,
                            Umax=U;
                            Tmax=T;
                            SbtTmax=SbtT/Te;
                            SftTmax=SftT/Te;
                    );

            );
            *END for i rotation

*Record Umax, Tmax
 ex=0;
 Loop (o,
            ex=ex+1;
            if (ex=dex,
                exr(o,so)=r; exv(o,so)=Umax; exav(o,so)=Tmax;
                exSbt(o,so)=SbtTmax;   exSft(o,so)=SftTmax;
             );

  );
*END Record


);
*END Z

);
*END Loop so

);
*END Loop sr


Execute_unload "EEP12-305.gdx" exr, exv, exav, exSbt, exSft,MVPs, name1,
namer, nameT, namev, namemvp, nameB, nameF;

Execute 'gdxxrw.exe EEP12-305.gdx par=exr rng=a3:k103 cdim=1 rdim=1
par=exav rng=m3:w103 cdim=1 rdim=1 par=exv rng=y3:aj103 cdim=1 rdim=1'

Execute 'gdxxrw.exe EEP12-305.gdx par=exsbt rng=ak3:au103 cdim=1 rdim=1
par=exsft rng=aw3:bg103 cdim=1 rdim=1 par=MVPs rng=b2 par=MVPs rng=n2
par=MVPs rng=z2 par=MVPs rng=al2 par=MVPs rng=ax2'
Execute 'gdxxrw.exe EEP12-305.gdx set=name1 rng=a2:a2 set=namev rng=z2:z2
set=namer rng=a4:a4 set=nameT rng=n2:n2 set=namemvp rng=a3:a3
set=namemvp rng=m3:m3 set=namemvp rng=y3:y3'
```

```
Execute 'gdxxrw.exe EEP12-305.gdx set=nameB rng=ak2:ak2 set=nameF
rng=aw2:aw2 set=namemvp rng=ak3:ak3 set=namemvp rng=aw3:aw3'
```

REFERENCES

Adams, D. M., Alig, R. J., McCarl, B. A., Callaway, J. M., & Winnett, S. M. (1996). An analysis of the impacts of public timber harvest policies on private forest management in the United States. *Forest Science, 42*(3), 343-358.

Adams, D. M., & Latta, G. S. (2005). Costs and regional impacts of restoration thinning programs on the national forests in eastern Oregon. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 35*(6), 1319-1330.

Adams, W. M., Aveling, R., Brockington, D., Dickson, B., Elliott, J., Hutton, J., et al. (2004). Biodiversity conservation and the eradication of poverty. *Science, 306*(5699), 1146-1148.

ADB (2007). *Key Indicators 2007: Inequality in Asia*.

Adis, J. (1990). Thirty million arthropod species - too many or too few? *Journal of Tropical Ecology, 6*(1), 115-118.

Alvarez, L. H. R., & Koskela, E. (2006). Does risk aversion accelerate optimal forest rotation under uncertainty? *Journal of Forest Economics, 12*(3), 171-184.

Alves, R. R. N., & Rosa, I. M. L. (2007). Biodiversity, traditional medicine and public health: where do they meet? *Journal of Ethnobiology and Ethnomedicine, 3*(1), 3-14.

Amacher, G. S., Koskela, E., & Ollikainen, M. (2004). Forest rotations and stand interdependency: ownership structure and timing of decisions. *Natural Resource Modeling 17*(1), 1-45.

An, D. T., & Ha, C. T. T. (2006). *Biodiversity in Vietnam*. Paper presented at the The 17th Data Sources in Asian-Ocenic Countries. Retrieved from dsao.codata.cn/conference/17th/Biodiversity%20in%20Vietnam.ppt

Angelsen, A. (2009). *"Reducing emissions from deforestation and forest degradation (REDD): an options assessment report."* Retrieved 19/06, 2011, from http://www.redd-oar.org/links/REDD-OAR_en.pdf.

Armsworth, P. R., Kendall, B. E., & Davis, F. W. (2004). An introduction to biodiversity concepts for environmental economists. *Resource and Energy Economics, 26*(2), 115-136.

Arnold, J. E. M. (1995). Social-economic benefits and issues in non-wood forest products use *Report of the international expert consultation on non-wood forest products* (pp. 89-124): FAO.

Arrow K., Cline W., Maler K., Munasinghe M., Squitieri R., Stiglitz J. (1996) Intertemporal equity, discounting, and economic efficiency. *Climate Change 1995: Economic and Social Dimensions of Climate Change:* Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change: 125.

Bandara, R., & Tisdell, C. (2003). Comparison of rural and urban attitudes to the conservation of Asian elephants in Sri Lanka: empirical evidence. *Biological Conservation, 110*(3), 327-342.

Bann, C. (2002). An overview of valuation techniques: advantages and limitations. *Asean biodiversity, 2*, 8-16.

Barbaro, L., Couzi, L., Bretagnolle, V., Nezan, J., & Vetillard, F. (2008). Multi-scale habitat selection and foraging ecology of the eurasian hoopoe (Upupa epops) in pine plantations. *Biodiversity and Conservation, 17*(5), 1073-1087.

Barlow, J., Araujo, I. S., Overal, W. L., Gardner, T. A., Mendes, F. D., Lake, I. R., et al. (2008). Diversity and composition of fruit-feeding butterflies in tropical Eucalyptus plantations. *Biodiversity and Conservation, 17*(5), 1089-1104.

Barlow, J., Gardner, T. A., Araujo, I. S., Avila-Pires, T. C., Bonaldo, A. B., Costa, J. E., et al. (2007). Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 18555-18560.

Barlow, J., Overal, W. L., Araujo, I. S., Gardner, T. A., & Peres, C. A. (2007). The value of primary, secondary and plantation forests for fruit-feeding butterflies in the Brazilian Amazon. *Journal of Applied Ecology, 44*(5), 1001-1012.

Bateman, I. J., Coombes, E., Fisher, B., Fitzherbert, E., Glew, D., & Naidoo, R. (2009). *Saving Sumatra's species: combining economics and ecology to define an efficient and self-sustaining program for inducing conservation within oil palm plantations*. Paper presented at the 17th EAERE Annual Conference.

Bateman, I. J., & Lovett, A. A. (2000). Estimating and valuing the carbon sequestered in softwood and hardwood trees, timber products and forest soils in Wales. *Journal of environmental management, 60*(4), 301-323.

Baumgartner, S., & Quaas, M. F. (2009). Ecological-economic viability as a criterion of strong sustainability under uncertainty. *Ecological Economics, 68*(7), 2008-2020.

Begon, M., Harper, J. L., & Townsend, C. R. (1996). *Ecology: Individuals, Populations and Communities*: Blackwell Publishing, Cambridge, MA.

Berrens, R. P. (2001). The safe minimum standard of conservation and endangered species: a review. *Environmental Conservation, 28*(2), 104-116.

Biosecurity New Zealand. (2009). Varroa mite. Retrieved 28/09/2010, from http://www.biosecurity.govt.nz/pests/varroa

Bishop, R. C. (1978). Endangered species and uncertainty - the economics of a safe minimum standard. *American Journal of Agricultural Economics, 60*(1), 10-18.

Blockstein, D. E. (1998). Lyme disease and the passenger pigeon? *Science, 279*(5358), 1831-+.

Briefing, A. I. (2008). Biodiversity, climate change and poverty: exploring the links. *Development*.

Brockerhoff, E. G., Ecroyd, C. E., Leckie, A. C., & Kimberley, M. O. (2003). Diversity and succession of adventive and indigenous vascular understorey plants in Pinus radiata plantation forests in New Zealand. *Forest Ecology and Management, 185*(3), 307-326.

Brockerhoff, E. G., Jactel, H., Parrotta, J. A., Quine, C. P., & Sayer, J. (2008). Plantation forests and biodiversity: oxymoron or opportunity? *Biodiversity and Conservation, 17*(5), 925-951.

Bui, D. T., & Hong, B. N. (2006). Payments for environmental services in Vietnam: Assessing an economic approach to sustainable forest management. *Economy and Environment Program for Southeast Asia*.

Bull, G. Q., Bazett, M., Schwab, O., Nilsson, S., White, A., & Maginnis, S. (2006). Industrial forest plantation subsidies: Impacts and implications. *Forest Policy and Economics, 9*(1), 13-31.

Bulte, E., & Engel, S. (2006). Conservation of tropical forests: addressing market failure. In R. López & M. A. Toman (Eds.), *Economic development and environmental sustainability: new policy options* (pp. 412-452): Oxford University Press, USA.

Bulte, E. H., & van Kooten, G. C. (2001). Harvesting and conserving a species when numbers are low: population viability and gambler's ruin in bioeconomic models. *Ecological Economics, 37*(1), 87-100.

Byers, B. A. (2000). *Understanding and influencing behaviors in conservation and natural resources management*. Washington, DC, USA: Biodiversity Support Program.

Calkin, D. E., Montgomery, C. A., Schumaker, N. H., Polasky, S., Arthur, J. L., & Nalle, D. J. (2002). Developing a production possibility set of wildlife species persistence and timber harvest value. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 32*(8), 1329-1342.

Caparros, A., Cerdá, E., Ovando, P., & Campos, P. (2010). Carbon sequestration with reforestations and biodiversity-scenic values. *Environmental and Resource Economics, 45*(1), 49-72.

Carey, A. B., Lippke, B. R., & Sessions, J. (1999). Intentional systems management: managing forests for biodiversity. *Journal of Sustainable Forestry, 9*(3), 83-125.

Cargill, M., Altshuler, D., Ireland, J., Sklar, P., Ardlie, K., Patil, N., et al. (1999). Characterization of single-nucleotide polymorphisms in coding regions of human genes. *Nature genetics, 22*(3), 231-238.

Caro, F., Constantino, M., Martins, I., & Weintraub, A. (2003). A 2-Opt tabu search procedure for the multiperiod forest harvesting problem with adjacency, greenup, old growth and even flow constraints. *Forest Science, 49*(5), 738-751.

Cashore, B., & McDermott, C. (2004). Global environmental forest policies: Canada as a constant case comparison of select forest practice regulations. *Vancouver, Canada: International Forest Resources*.

CBD (1992). The Convention on Biological Diversity. Retrieved 29/10/2009, from http://www.cbd.int/convention/articles.shtml?a=cbd-02

CBD (2002). Forest biological diversity. 25/09/2007, from http://www.cbd.int/decisions/cop-06.shtml?m=COP-06&id=7196&lg=0

Chapin, F. S., Walker, B. H., Hobbs, R. J., Hooper, D. U., Lawton, J. H., Sala, O. E., et al. (1997). Biotic control over the functioning of ecosystems. *Science, 277*(5325), 500-504.

Chisholm, R. A. (2010). Trade-offs between ecosystem services: Water and carbon in a biodiversity hotspot. *Ecological Economics, 69*(10), 1973-1987.

Chladna, Z. (2007). Determination of optimal rotation period under stochastic wood and carbon prices. [Article]. *Forest Policy and Economics, 9*(8), 1031-1045.

Ciriacy-Wantrup, S. V. (1952). *Resource Conservation: Economics and Policies* Berkeley: University of California Press.

Clark, C. W. (1973). Profit maximization and the extinction of animal species. *The Journal of Political Economy, 81*(4), 950-961.

Clarke, H. R., & Reed, W. J. (1989). The tree-cutting problem in a stochastic environment : The case of age-dependent growth. *Journal of Economic Dynamics and Control, 13*(4), 569-595.

Clout, M. N. (1984). Improving exotic forests for native birds. *New Zealand Journal of Forestry, 29*, 193-200.

Cooney, R., & Dickson, B. (2004). *Biodiversity and the precautionary principle : risk and uncertainty in conservation and sustainable use* London: Earthscan.

Creedy, J., & Wurzbacher, A. D. (2001). The economic value of a forested catchment with timber, water and carbon sequestration benefits. *Ecological Economics, 38*(1), 71-83.

Crowards, T. M. (1998). Safe Minimum Standards: costs and opportunities. *Ecological Economics, 25*(3), 303-314.

Cubbage, F., Harou, P., & Sills, E. (2007). Policy instruments to enhance multi-functional forest management. *Forest Policy and Economics, 9*(7), 833-851.

Curtis, R. O. (1997). The role of extended rotations. In K. A. Kohm & J. F. Franklin (Eds.), *Creating a forestry for the 21st century: the science of ecosystem management* (pp. 165-170). Washington: Island Press.

Daniels, R. J. R., Hegde, M., & Gadgil, M. (1990). Birds of the man-made ecosystems - the plantations. *Proceedings of the Indian Academy of Sciences-Animal Sciences, 99*(1), 79-89.

Daigneault A.J., Miranda M.J., Sohngen B. (2010) Optimal Forest Management with Carbon Sequestration Credits and Endogenous Fire Risk. *Land Economics*: 86 155.

Dasgupta, S., Mody, A., Roy, S., & Wheeler, D. (2001). Environmental regulation and development: a cross-country empirical analysis. *Oxford Development Studies, 29*(2), 173-187.

Davis, L. S., & Johnson, K. N. (2001). *Forest management: to sustain ecological, economic, and social values*. New York: McGraw-Hill Book Company.

Day, B. A., & Smith, W. A. (1996). *The applied behavior change (ABC) framework: environmental applications*. Washington, DC, USA: Academy for Educational Development.

Deke, O. (2007). *Environmental policy instruments for conserving global biodiversity*. Berlin, Germany: Springer Verlag.

Diaz-Balteiro, L., & Rodriguez, L. C. E. (2006). Optimal rotations on Eucalyptus plantations including carbon sequestration - A comparison of results in Brazil and Spain. *Forest Ecology and Management, 229*(1-3), 247-258.

Diaz, L. (2006). Influences of forest type and forest structure on bird communities in oak and pine woodlands in Spain. *Forest Ecology and Management, 223*(1-3), 54-65.

Dixit, A. K., & Pindyck, R. S. (1994). *Investment under uncertainty*. New Jersey, USA: Princeton University Press.

Doherty, P. F., Marschall, E. A., & Grubb, T. C. (1999). Balancing conservation and economic gain: a dynamic programming approach. *Ecological Economics, 29*(3), 349-358.

Donald, P. F., Fuller, R. J., Evans, A. D., & Gough, S. J. (1998). Effects of forest management and grazing on breeding bird communities in plantations of broadleaved and coniferous trees in western England. *Biological Conservation, 85*(1-2), 183-197.

Drucker, A. G. (2006). An application of the use of safe minimum standards in the conservation of livestock biodiversity. *Environment and Development Economics, 11*, 77-94.

Duelli, P., & Obrist, M. K. (2003). Biodiversity indicators: the choice of values and measures. *Agriculture, Ecosystems & Environment, 98*(1-3), 87-98.

Dufour, A., Gadallah, F., Wagner, H. H., Guisan, A., & Buttler, A. (2006). Plant species richness and environmental heterogeneity in a mountain landscape: effects of variability and spatial configuration. *Ecography, 29*(4), 573-584.

Durst, P. B., McKenzie, P. J., Brown, C. L., & Appanah, S. (2006). Challenges facing certification and eco-labelling of forest products in developing countries. *International Forestry Review, 8*(2), 193-200.

Ehrenfeld, D. (1986). Why put a value on biodiversity? In E. O. Wilson (Ed.), *The National Forum on Biodiversity* (pp. 212). Washington, D. C.: Natl Academy Press.

Eiswerth, M. E., & van Kooten, G. C. (2009). The ghost of extinction: Preservation values and minimum viable population in wildlife models. *Ecological Economics, 68*(7), 2129-2136.

Engel, S., Pagiola, S., & Wunder, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics, 65*(4), 663-674.

Englin, J., & Callaway, J. (1993). Global climate change and optimal forest management *Natural Resource Modeling, 7*(3), 191-202.

Eppink, F. V., & van den Bergh, J. (2007). Ecological theories and indicators in economic models of biodiversity loss and conservation: A critical review. *Ecological Economics, 61*(2-3), 284-293.

FAO (1995). Non-wood forest products for rural income and sustainable forestry. *Non Wood Forest Products Series no 7* Retrieved 28/09/2010, from http://www.fao.org/docrep/V9480E/v9480e00.HTM#Contents

FAO (1996). *Forestry and Food Security*. Rome: Food and Agriculture Organization.

FAO (1997). *Regional Study on Wood Energy Today and Tomorrow in Asia*. Rome: Food and Agriculture Organization.

FAO (2006). *Global Forest Resources Assessment 2005*. Rome.

FAO (2008). *Forests and energy. Key issues*. Rome: Food and Agriculture Organization.

FAO (2009a). *The State of Food Insecurity in the World in 2009* (Vol. 399). Rome: Food and Agriculture Organization.

FAO (2009b). *The State of World Fisheries and Aquaculture 2008*. Rome: Food and Agriculture Organization.

FAO (2009c). *Wood energy*. Rome: Food and Agriculture Organization.

FAO (2007). *State of the World's Forests 2007* Rome.

Faustmann, M. (1849). Calculation of the value which forest land and immature stands possess for forestry. *Journal of Forest Economics, 1(1995)*(1), 7-44.

Ferraro, P. J. (2001). Global habitat protection: limitations of development interventions and a role for conservation performance payments. *Conservation Biology, 15*(4), 990-1000.

Ferraro, P. J., & Kiss, A. (2003). Will direct payments help biodiversity? (Response). *Science, 299*(5615), 1981-1982.

Fink A. (2008) *How to conduct surveys: A step-by-step guide*: Sage Publications, Inc.

Forneri, C., Blaser, J., Jotzo, F., & Robledo, C. (2006). Keeping the forest for the climate's sake: avoiding deforestation in developing countries under the UNFCCC. *Climate Policy, 6*(3), 275-294.

Franklin, E. (1980). Evolutionary change in small populations. In M. E. Soulé & B. A. Wilcox (Eds.), *Conservation biology: an evolutionary-ecological perspective* (pp. 135-149): Sinauer Associates Sunderland, MA.

Franklin, J. D., Berg, D. T., & Tappeiner, J. (1997). Alternative Silvicultural Approaches to Timber Harvesting: Variable Retention Harvest Systems. In K. A. Kohm & J. F. Franklin (Eds.), *Creating a forestry for the 21st century: the science of ecosystem management* (pp. 111-139). Washington: Island Press.

Franklin, J. F. (1993). Preserving biodiversity - species, ecosystems, or landscapes? [Article]. *Ecological Applications, 3*(2), 202-205.

FSC (2010). About FSC (Forest Stewardship Council). Retrieved 28/09/2010, from http://www.fsc.org/about-fsc.html

Gámez, R. (2007). The link between biodiversity and sustainable development: Lessons from INBio's bioprospecting programme in Costa Rica. In C. McManis (Ed.), *Biodiversity and the law: intellectual property, biotechnology and traditional knowledge* (pp. 77-90). London, UK: Earthscan.

Gaston, K. J. (1991). The magnitude of global insect species richness. *Conservation Biology, 5*(3), 283-296.

Gaston, K. J., & Spicer, J. I. (2004). *Biodiversity: an introduction*. Oxford, UK: Blackwell.

Gibbons, P., & Lindenmayer, D. B. (2007). Offsets for land clearing: No net loss or the tail wagging the dog? *Ecological Management and Restoration, 8*(1), 26-31.

Gong, Y., Bull, G., & Baylis, K. (2010). Participation in the world's first clean development mechanism forest project: The role of property rights, social capital and contractual rules. *Ecological Economics, 69*(6), 1292-1302.

Gordon, I., & Ayiemba, W. (2003). Harnessing butterfly biodiversity for improving livelihoods and forest conservation: the Kipepeo Project. *The Journal of Environment & Development, 12*(1), 82-86.

Green, R. J., & Jones, D. N. (2010). *Practices, needs and attitudes of bird-watching tourists in Australia* Gold Coast: CRC for Sustainable Tourism Pty Ltd.

Grieg-Gran, M., Porras, I., & Wunder, S. (2005). How can market mechanisms for forest environmental services help the poor? Preliminary lessons from Latin America. *World Development, 33*(9), 1511-1527.

Groves R.M., Fowler F.J., Couper M.P., Lepkowski J.M., Singer E. (2009) *Survey methodology*: John Wiley & Sons Inc.

Guenette, J. S., & Villard, M. A. (2005). Thresholds in forest bird response to habitat alteration as quantitative targets for conservation. *Conservation Biology, 19*(4), 1168-1180.

Guldin, R. W. (2003). Forest science and forest policy in the Americas: building bridges to a sustainable future. *Forest Policy and Economics, 5*(4), 329-337.

Gullison, R. E. (2003). Does forest certification conserve biodiversity? *Oryx, 37*(02), 153-165.

Gurluk, S., & Ward, F. A. (2009). Integrated basin management: Water and food policy options for Turkey. *Ecological Economics, 68*(10), 2666-2678.

Guthrie, G., & Kumareswaran, D. (2009). Carbon Subsidies, Taxes and Optimal Forest Management. [Article]. *Environmental & Resource Economics, 43*(2), 275-293.

Gutierrez, V. H., Zapata, M., Sierra, C., Laguado, W., & Santacruz, A. (2006). Maximizing the profitability of forestry projects under the Clean Development Mechanism using a forest management optimization model. *Forest Ecology and Management, 226*(1-3), 341-350.

Gutrich, J., & Howarth, R. B. (2007). Carbon sequestration and the optimal management of New Hampshire timber stands. *Ecological Economics, 62*(3-4), 441-450.

Ha, H. M., Noordwijk, M. v., & Thuy, P. T. (Eds.). (2008). *Payment for environmental services: experiences and lessons in Vietnam*. Hanoi, Vietnam: World Agroforestry Centre, ICRAF Vietnam.

Haigh, J. (2005). *Probability models*. Great Britain: Springer-Verlag London Limited.

Harper, J. L., & Hawksworth, D. L. (1996). *Biodiversity: measurement and estimation*. London: Chapman & Hall.

Hartman, R. (1976). The harvesting decision when a standing forest has value. *Economic Inquiry, 14* (1), 52-58.

Hassan, R. M., Scholes, R., & Ash, N. (2005). *Ecosystems and human well-being: current state and trends: findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment*: Washington, DC: Island Press.

Hawksworth, D. L. (1991). The fungal dimension of biodiversity - Magnitude, singificance, and conservation [Article]. *Mycological Research, 95*, 641-655.

Heal, G. (2004). Economics of biodiversity: an introduction. *Resource and Energy Economics, 26*(2), 105-114.

Hill, M., Eames, J. C., Trai, L. E. T., & Cu, N. (2001). Population sizes, status and habitat associations of forest birds in Chu Yang Sin Nature Reserve, Dak Lak province, Vietnam. *Bird Conservation International, 11*(01), 49-70.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics, 4*(1), 1-23.

Horne, P. (2006). Forest owners' acceptance of incentive based policy instruments in forest biodiversity conservation - A choice experiment based approach. *Silva Fennica, 40*(1), 169-178.

Hurme, E., Kurttila, M., Monkkonen, M., Heinonen, T., & Pukkala, T. (2007). Maintenance of flying squirrel habitat and timber harvest: a site-specific spatial model in forest planning calculations. *Landscape Ecology, 22*(2), 243-256.

Hurme, E., Monkkonen, M., Nikula, A., Nivala, V., Reunanen, P., Heikkinen, T., et al. (2005). Building and evaluating predictive occupancy models for the

Siberian flying squirrel using forest planning data. *Forest Ecology and Management, 216*(1-3), 241-256.

Hutton, J., Ada, W., & Murombedzi, J. (2005). Back to the barriers? Changing narratives in biodiversity conservation. *Forum for Development Studies, 32*(2), 341–371.

Hvenegaard, G. T., Butler, J. R., & Krystofiak, D. K. (1989). Economic values of bird watching at point Pelee National Park, Canada. *Wildlife Society Bulletin, 17*(4), 526-531.

Hyytiainen, K., & Tahvonen, O. (2002). Economics of forest thinnings and rotation periods for Finnish conifer cultures. *Scandinavian Journal of Forest Research, 17*(3), 274-288.

Hyytiainen, K., & Tahvonen, O. (2003). Maximum sustained yield, forest rent or Faustmann: Does it really matter? *Scandinavian Journal of Forest Research, 18*(5), 457-469.

Insley, M. (2002). A real options approach to the valuation of a forestry investment. *Journal of Environmental Economics and Management, 44*(3), 471-492.

IUCN (1993). *Parks for Life: Report of the IVth World Congress on National Parks and Protected Areas*. Gland, Switzerland.

Janota, J. J., & Broussard, S. R. (2008). Examining private forest policy preferences. *Forest Policy and Economics, 10*(3), 89-97.

Jetz, W., Carbone, C., Fulford, J., & Brown, J. H. (2004). The scaling of animal space use. *Science, 306*(5694), 266-268.

Judd, K. L. (1998). *Numerical methods in economics*. Massachusetts: The MIT Press.

Juutinen, A. (2008). Old-growth boreal forests: Worth protecting for biodiversity? *Journal of Forest Economics, 14*(4), 242-267.

Juutinen, A., & Mönkkönen, M. (2004). Testing alternative indicators for biodiversity conservation in old-growth boreal forests: ecology and economics. *Ecological Economics, 50*(1-2), 35-48.

Katila, M., & Puustjärvi, E. (2004). Markets for forest environmental services: reality and potential. *Unasylva 219*(55), 53-58.

Keenan, R., Lamb, D., Woldring, O., Irvine, T., & Jensen, R. (1997). Restoration of plant biodiversity beneath tropical tree plantations in Northern Australia. *Forest Ecology and Management, 99*(1-2), 117-131.

Khajuria, R. P., Laaksonen-Craig, S., & Kant, S. (2008). A marginal cost analysis of trade-offs in old-growth preservation in Ontario. *Forest Policy and Economics, 10*(5), 326-335.

Kiesecker, J. M., Copeland, H., Pocewicz, A., Nibbelink, N., McKenney, B., Dahlke, J., et al. (2009). A framework for implementing biodiversity offsets: selecting sites and determining scale. *Bioscience, 59*(1), 77-84.

Kilgore, M. A., & Blinn, C. R. (2004). Policy tools to encourage the application of sustainable timber harvesting practices in the United States and Canada. *Forest Policy and Economics, 6*(2), 111-127.

Koenig, W. D. (1988). On determination of viable population size in birds and mammals. *Wildlife Society Bulletin, 16*(2), 230-234.

Koskela, E., & Ollikainen, M. (2001). Optimal Private and Public Harvesting under Spatial and Temporal Interdependence. *Forest Science, 47*(4), 484-496.

Koskela, E., Ollikainen, M., & Pukkala, T. (2007a). Biodiversity conservation in commercial boreal forestry: The optimal rotation age and retention tree volume. *Forest Science, 53*(3), 443-452.

Koskela, E., Ollikainen, M., & Pukkala, T. (2007b). Biodiversity policies in commercial boreal forests: Optimal design of subsidy and tax combinations. *Forest Policy and Economics, 9*(8), 982-995.

Köthke, M., & Dieter, M. (2010). Effects of carbon sequestration rewards on forest management--An empirical application of adjusted Faustmann Formulae. *Forest Policy and Economics, In Press, Corrected Proof.*

Kruger, C. R. (2010). *Public preferences for SFM: Case studies in tenure policy and forest certification.* University of Alberta, Alberta.

Laarman, J. G. (1997). Government policies affecting forests in Latin America. *An agenda for discussion. Environment Division, Social Sectors and Sustainable Development Department, Inter-American Development Bank. Washington DC USA*.

Lacey, H. (2005). *Is science value free?: values and scientific understanding*. London: Taylor & Francis Group.

Lange, D. (1998). *Europe's medicinal and aromatic plants: their use, trade and conservation*.

Lantschner, M. V., Rusch, V., & Peyrou, C. (2008). Bird assemblages in pine plantations replacing native ecosystems in NW Patagonia. *Biodiversity and Conservation, 17*(5), 969-989.

Latta, G., & Montgomery, C. (2007). Economic considerations in managing for older-forest structure. In T. B. Harrington & G. E. Nicholas (Eds.), *Managing for Wildlife Habitat in Westside Production Forests* (pp. 95-104). Oregon: USDA.

Lawson S., MacFaul L. (2010) *Illegal Logging and Related Trade*. London: The Royal Institute of International Affairs.

Lawton, J. H., Bignell, D. E., Bolton, B., Bloemers, G. F., Eggleton, P., Hammond, P. M., et al. (1998). Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature, 391*(6662), 72-76.

Lazdinis, M., Carver, A., Tõnisson, K., & Silamikele, I. (2005). Innovative use of forest policy instruments in countries with economies in transition: experience of the Baltic States. *Forest Policy and Economics, 7*(4), 527-537.

Leadley, P., Pereira, H.M., Alkemade, R.,, Fernandez-Manjarrés, J. F., Proença, V., Scharlemann, J.P.W.,, & Walpole, M. J. (2010). *Biodiversity Scenarios: Projections of 21st century change in biodiversity and associated ecosystem services.*: Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 50, 132 pages.

Leuschner, W. A. (1990). *Forest regulation, harvest scheduling, and planning techniques*. New York: John Wiley & Sons.

Lien, G., Størdal, S., & Baardsen, S. (2007). Technical efficiency in timber production and effects of other income sources. *Small-Scale Forestry, 6*(1), 65-78.

Light, M. E., Sparg, S. G., Stafford, G. I., & van Staden, J. (2005). Riding the wave: South Africa's contribution to ethnopharmacological research over the last 25 years. *Journal of Ethnopharmacology, 100*(1-2), 127-130.

Lindenmayer, D., & Franklin, J. F. (2002). *Conserving forest biodiversity: a comprehensive multiscaled approach*. Washington, DC: Island Press.

Lindenmayer, D. B., Knight, E. J., Crane, M. J., Montague-Drake, R., Michael, D. R., & MacGregor, C. I. (2010). What makes an effective restoration planting for woodland birds? *Biological Conservation, 143*(2), 289-301.

Lindhjem, H. (2007). 20 years of stated preference valuation of non-timber benefits from Fennoscandian forests: A meta-analysis. *Journal of Forest Economics, 12*(4), 251-277.

Litwin M.S. (1995) *How To Measure Survey Reliability and Validity*. The Survey Kit, Volume 7: SAGE Publications, Inc.

Loomes, G., & Sugden, R. (1982). Regret theory: An alternative theory of rational choice under uncertainty. *The Economic Journal, 92*(368), 805-824.

Loomis, J. B., & White, D. S. (1996). Economic benefits of rare and endangered species: Summary and meta-analysis. *Ecological Economics, 18*(3), 197-206.

Lovera, S. (2005). Environmental markets impoverish the poor. *The Katoomba Group's Ecosystems Marketplace*, 27/09/2010, from http://ecosystemmarketplace

Luce, R., & Raiffa, H. (1989). *Games and decisions: Introduction and critical survey*: Dover Pubns.

Luck, G. W., & Korodaj, T. N. (2008). Stand and landscape-level factors related to bird assemblages in exotic pine plantations: Implications for forest management. *Forest Ecology and Management, 255*(7), 2688-2697.

Mac Nally, R., Fleishman, E., Bulluck, L. P., & Betrus, C. J. (2004). Comparative influence of spatial scale on beta diversity within regional assemblages of birds and butterflies. [Review]. *Journal of Biogeography, 31*(6), 917-929.

Maclaurin, J., & Sterelny, K. (2008). *What is biodiversity?* London: The University of Chicago Press.

Magurran, A. E. (1988). *Ecological diversity and its measurement*: Princeton University Press, Princeton, NJ.

MARD (2003). *Yield table of 14 dominant tree species in productive planted forests in Vietnam*. Hanoi: Agriculture.

MARD (2005). *Decision 38 QD38-2005-BNN Costs regulated for planting trees in plantation forests (Dinh muc kinh te ky thuat trong rung).*

MARD (2006). Vietnam's joining WTO: Opportunities and challenging for Vietnam's forest enterprises. *News on Five Million Hectare Program, 2 (2006).*

MARD (2007). Forest Statistics. Retrieved 12/01/2010, from http://www.kiemlam.org.vn/Desktop.aspx/News/So-lieu-dien-bien-rung-hang-nam/

Maron, M., Dunn, P. K., McAlpine, C. A., & Apan, A. (2010). Can offsets really compensate for habitat removal? The case of the endangered red-tailed black-cockatoo. *Journal of Applied Ecology, 47*(2), 348-355.

Martin-Lopez, B., Montes, C., & Benayas, J. (2008). Economic valuation of biodiversity conservation: the meaning of numbers. *Conservation Biology, 22*(3), 624-635.

Mayer, P. (2006). Biodiversity-the appreciation of different thought styles and values helps to clarify the term. *Restoration Ecology, 14*(1), 105-111.

McElwee, P. (2004). You say illegal, I say legal. *Journal of Sustainable Forestry, 19*(1), 97-135.

McKenney, B. A., & Kiesecker, J. M. (2010). Policy Development for Biodiversity Offsets: A Review of Offset Frameworks. *Environmental Management*(45), 165-176.

MERCK (1991). Merck-INBIO Plant Agreement. Retrieved 03/12/2009, from http://www1.american.edu/ted/MERCK.HTM

Meyer, C. A. (2008). NGOs and environmental public goods: institutional alternatives to property rights. *Development and Change, 27*(3), 453-474.

Meyfroidt, P., & Lambin, E. F. (2008). Forest transition in Vietnam and its environmental impacts. *Global Change Biology, 14*(6), 1319-1336.

Milne, S., & Niesten, E. (2009). Direct payments for biodiversity conservation in developing countries: practical insights for design and implementation. *Oryx, 43*(4), 530-541.

Miranda, M. J., & Fackler, P. L. (2002). *Applied computational economics and finance*. Massachusetts: The MIT Press.

Mitra, S. S., & Sheldon, F. H. (1993). Use of an exotic tree plantation by bornean lowland forest birds. [Article]. *Auk, 110*(3), 529-540.

Mitra, T., and Wan, Y. H. (1985). Some Theoretical Results on the Economics of Forestry *The Review of Economic Studies, 52*(2), 263-282.

Mitra, T., & Wan, H. Y. (1986). On the Faustmann solution to the forest management problem *Journal of Economic Theory, 40*(2), 229-249.

Moilanen, A., van Teeffelen, A. J. A., Ben-Haim, Y., & Ferrier, S. (2009). How Much Compensation is Enough? A Framework for Incorporating

Uncertainty and Time Discounting When Calculating Offset Ratios for Impacted Habitat. *Restoration Ecology, 17*(4), 470-478.

Moning, C., & Muller, J. (2008). Environmental key factors and their thresholds for the avifauna of temperate montane forests. *Forest Ecology and Management, 256*(5), 1198-1208.

MONRE (2005). Project No. 264 of planting trees in Thai Nguyen goes bankrupt, Retrieved 30 July 2009, http://www.nea.gov.vn/thongtinmt/noidung/btn_4_7_05.htm.

Montgomery, C. A., Latta, G. S., & Adams, D. M. (2006). The cost of achieving old-growth forest structure. *Land Economics, 82*(2), 240-256.

Moore M.A., Boardman A.E., Vining A.R., Weimer D.L., Greenberg D.H.. (2004) "Just give me a number!" Practical values for the social discount rate. *Journal of Policy Analysis and Management:* 23 789-812.

Moore, S. E., & Allen, H. L. (1999). Plantation forestry. In M. L. J. Hunter (Ed.), *Maintaining Biodiversity in Forest Ecosystems* (pp. 400-433). New York: Cambridge University Press.

Motoh, T. (2004). Optimal natural resources management under uncertainty with catastrophic risk. *Energy Economics, 26*(3), 487-499.

Moyle, B. (2003). Regulation, conservation and incentives. In S. Oldfield (Ed.), *The trade in wildlife: regulation for conservation*. London: Earthscan Publications Ltd.

Murray, B. C., & Abt, R. C. (2001). Estimating price compensation requirements for eco-certified forestry. *Ecological Economics, 36*(1), 149-163.

Naik, G. (1997). Joint forest management: Factors influencing household participation. *Economic and Political Weekly, 32*(48), 3084-3089.

Najera, A., & Simonetti, J. (2010). Enhancing Avifauna in Commercial Plantations. *Conservation Biology, 24*(1), 319-324.

Naka, K., Hammett, A. L., & Stuart, W. B. (2000). Constraints and opportunities to forest policy implementation in Albania. *Forest Policy and Economics, 1*(2), 153-163.

New, T. R. (1994). Butterfly ranching: sustainable use of insects and sustainable benefit to habitats. *Oryx, 28*(03), 169-172.

Nguyen, N. B., Nguyen, V. T., Bui, C. N., & Trinh, Q. T. (2006). Why do farmers choose to harvest small-sized timber?–A Survey in Yen Bai Province, Northern Vietnam.

Nguyen, T. Q. (2009). The Vietnam wood-processing industry after two year joining WTO. *E-journal of Enterprise Culture* Retrieved 30/07/2009, from http://www.vhdn.vn/index.php?option=com_content&view=article&id=5514:nganh-cong-nghiep-che-bien-go-viet-nam-sau-2-nam-gia-nhap-wto&catid=35:kinh-t

Nicholson, E., Westphal, M. I., Frank, K., Rochester, W. A., Pressey, R. L., Lindenmayer, D. B., et al. (2006). A new method for conservation planning for the persistence of multiple species. *Ecology Letters, 9*(9), 1049-1060.

Nordhaus, W. D. (2007). The Challenge of Global Warming: Economic Models and Environmental Policy. *Yale Univ., New Haven, CT*.

Norton, B. (1988). Commodity, amenity, and morality: the limits of quantification in valuing biodiversity. In E. O. Wilson (Ed.), *Biodiversity* (pp. 200-205). Washington, DC: National Academy Press.

Norton, D. A. (1999). Forest reserves. In M. L. Hunter (Ed.), *Maintaining biodiversity in forest ecosystems* (pp. 525-555). Cambridge: Cambridge University Press.

Norton, D. A. (2009). Biodiversity Offsets: Two New Zealand Case Studies and an Assessment Framework. *Environmental Management, 43*(4), 698-706.

Økland, B. (1996). Unlogged forests: important sites for preserving the diversity of mycetophilids (Diptera: Sciaroidea). *Biological Conservation, 76*(3), 297-310.

Oonyu, J. (2009). Conservation Education and the Attitudes of Local Communities Living Adjacent to Mt. Elgon National Park, Uganda. *Applied Environmental Education & Communication, 8*(3), 153-164.

Pagiola, S., Bishop, J., & Landell-Mills, N. (2004). *Selling forest environmental services: market-based mechanisms for conservation and development*: Earthscan Publications.

Paillet, Y., Berges, L., Hjalten, J., Ódor, P., Avon, C., Bernhardt-Romermann, M., et al. (2010). Biodiversity Differences between Managed and Unmanaged Forests: Meta-Analysis of Species Richness in Europe. *Conservation Biology, 24*(1), 101-112.

Pawson, S. M., Brockerhoff, E. G., Meenken, E. D., & Didham, R. K. (2008). Non-native plantation forests as alternative habitat for native forest beetles in a heavily modified landscape. *Biodiversity and Conservation, 17*(5), 1127-1148.

Pawson, S. M., Brockerhoff, E. G., Norton, D. A., & Didham, R. K. (2006). Clear-fell harvest impacts on biodiversity: past research and the search for harvest size thresholds. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 36*(4), 1035-1046.

Pearce, D., & Moran, D. (1994). *The economic value of Biodiversity. IUCN–The World Conservation Union*. London: Earthscan Publications.

Pearce, D., Moran, D., & Biller, D. (2002). *Handbook of Biodiversity valuation: A guide for policy makers*. Paris: OECD-Organisation for Economic Co-operation and Development.

Pearman, P. B., & Weber, D. (2007). Common species determine richness patterns in biodiversity indicator taxa. *Biological Conservation, 138*(1-2), 109-119.

Pearson, D. L. (1996). Selecting indicator taxa for the quantitative assessment of biodiversity. In J. L. Harper & D. L. Hawksworth (Eds.), *Biodiversity: measurement and estimation* (pp. 75-79). London: Chapman & Hall.

Perlman, D. L., & Adelson, G. (1997). *Biodiversity: exploring values and priorities in conservation*. Massachusetts, USA: Wiley-Blackwell.

Phelps, J., E. L. Webb, et al. (2010). "Does REDD+ Threaten to Recentralize Forest Governance?" Science **328**(5976): 312.Phu, N. T. (2008). *Ve chi tra dich vu moi truong rung o Viet Nam (About payment for environmental services in Vietnam).* Retrieved from http://cmsdata.iucn.org/downloads/pes_nguyen_tuan_phu.pdf.

Pimentel, D., McNair, M., Duck, L., Pimentel, M., & Kamil, J. (1997). The value of forests to world food security. [Review]. *Human Ecology, 25*(1), 91-120.

Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics, 52*(3), 273-288.

Polasky, S., Nelson, E., Lonsdorf, E., Fackler, P., & Starfield, A. (2005). Conserving species in a working landscape: land use with biological and economic objectives. *Ecological Applications, 15*(4), 1387-1401.

Pouta, E. (2005). Sensitivity to scope of environmental regulation in contingent valuation of forest cutting practices in Finland. *Forest Policy and Economics, 7*(4), 539-550.

Powell, I., White, A., & Landell-Mills, N. (2005). Developing markets for the ecosystem services of forests. In P. J. Shah & V. Maitra (Eds.), *Terracotta reader: a market approach to the environment* (pp. 205). New Delhi: Academic Foundation in association with Centre for Civil Society, New Delhi.

Price C., Willis R. (2011) The multiple effects of carbon values on optimal rotation. *Journal of Forest Economics.*

Purvis, A., & Hector, A. (2000). Getting the measure of biodiversity. *Nature, 405*(6783), 212-219.

Ralambo, J. (1994). The role of local people in the successful maintenance of protected areas in Madagascar. *Environmental Conservation, 21*(02), 115-120.

Ready, R. C., & Bishop, R. C. (1991). Endangered species and the safe minimum standard. *American Journal of Agricultural Economics, 73*(2), 309-312.

Reed, D. H., O'Grady, J. J., Brook, B. W., Ballou, J. D., & Frankham, R. (2003). Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates. *Biological Conservation, 113*(1), 23-34.

Reed, W. J., & Clarke, H. R. (1990). Harvest decicions and asset valuation for biological resources exhibiting size-dependent stochastic growth. *International Economic Review, 31*(1), 147-169.

Richards, K. R., & Stokes, C. (2004). A review of forest carbon sequestration cost studies: a dozen years of research. *Climatic Change, 63*(1), 1-48.

Rijsoort, J., & Pater, C. (2000). *Non-timber forest products (NTFPs): their role in sustainable forest management in the tropics*. Wageningen: National Reference Centre for Nature Management.

Rivas Palma, R. M. (2008). *Environmental and Social Values from Plantation Forests: A Study in New Zealand with Focus on the Hawke's Bay Region* University of Canterbury, Chrischurch.

Roe, D., Mayers, J., Grieg-Gran, M., Kothari, A., Fabricius, C., & Hughes, R. (2000). *Evaluating Eden: Exploring the myths and realities of community-based wildlife management* (Vol. Evaluating Eden Series 8). London.

Romero, C., & Andrade, G. I. (2004). International conservation organizations and the fate of local tropical forest conservation initiatives. *Conservation Biology, 18*(2), 578-580.

Rose, S. K., & Chapman, D. (2003). Timber harvest adjacency economies, hunting, species protection, and old growth value: seeking the dynamic optimum. *Ecological Economics, 44*(2-3), 325-344.

Ross, S. (2007). *Introduction to probability models*. San Diego: Academic Press.

Salamon, L. M., & Lund, M. S. (1989). The changing tools of government action: An overview *Beyond privatization: the tools of government action* (pp. 3-22). Washington, DC.: The Urban Institute Press.

Sanderson, S. E., & Redford, K. H. (2003). Contested relationships between biodiversity conservation and poverty alleviation. *Oryx, 37*(04), 389-390.

Sax, D. F. (2002). Equal diversity in disparate species assemblages: a comparison of native and exotic woodlands in California. *Global Ecology and Biogeography, 11*(1), 49-57.

Schaaf, K. A., & Broussard, S. R. (2006). Private forest policy tools: A national survey exploring the American public's perceptions and support. *Forest Policy and Economics, 9*(4), 316-334.

Schneider, A., & Ingram, H. (1990). Behavioral assumptions of policy tools. *The Journal of Politics, 52*(2), 510-529.

Schumaker, N. H. (1999). *A users guide to the PATCH model*: National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

Scott, J. M., Davis, F., Csuti, B., Noss, R., Butterfield, B., Groves, C., et al. (1993). Gap analysis - A geographic approach to protection of biological diversity. [Article]. *Wildlife Monographs*(123), 1-41.

Seaton, R., Minot, E. O., & Holland, J. D. (2010). Variation in bird species abundance in a commercial pine plantation in New Zealand. *New Zealand Journal of Forestry, 54*(4), 3-11.

Shaffer, M. L. (1981). Minimum population sizes for species conservation. *BioScience, 31*(2), 131-134.

Shaffer, M. L., Watchman, L. H., Snape, W. J., & Latchis, I. K. (2002). Population viability analysis and conservation policy In S. R. Beissinger, McCullough, D.R. (Ed.), *Population viability analysis* (pp. 123–142). Chicago: University of Chicago Press.

Sheldon, F. H., Styring, A., & Hosner, P. A. (2010). Bird species richness in a Bornean exotic tree plantation: A long-term perspective. *Biological Conservation, 143*(2), 399-407.

Simpson, R. D. (2004). Conserving Biodiversity through Markets: A better approach. *Bozeman (MT): Property and Environment Research Center*.

SIRIFIN. (2007). Government bonds. Retrieved 28/09/2010, from http://sirifin.vn/info/article.aspx?newsid=52940;exchange=HA

Smith, D. M., Larson, B. C., Kelty, M. J., & Ashton, P. M. S. (1997). *The practice of silviculture: applied forest ecology*: John Wiley & Sons. New York. US.

Smith, G. F., Gittings, T., Wilson, M., French, L., Oxbrough, A., O'Donoghue, S., et al. (2008). Identifying practical indicators of biodiversity for stand-level management of plantation forests. *Biodiversity and Conservation, 17*(5), 991-1015.

Sodhi, N. S., Koh, L. P., Clements, R., Wanger, T. C., Hill, J. K., Hamer, K. C., et al. (2010). Conserving Southeast Asian forest biodiversity in human-modified landscapes. *Biological Conservation, 143*(10), 2375-2384.

Sodhi, N. S., Posa, M., Lee, T., Bickford, D., Koh, L., & Brook, B. (2010). The state and conservation of Southeast Asian biodiversity. *Biodiversity and conservation, 19*(2), 317-328.

Sohngen, B. (2009). An analysis of forestry carbon sequestration as a response to climate change. Retrieved 16/10/2009, from http://aede.osu.edu/people/sohngen.1/forests/ccforest.htm

Spitzer, K., Novotny, V., Tonner, M., & Leps, J. (1993). Habitat preferences, distribution and seasonality of the butterflies (Lepidoptera, Papilionoidea) in a montane tropical rain-forest, Vietnam *Journal of Biogeography, 20*(1), 109-121.

SSC (2007). Government Bonds. Retrieved 07/09/2010, from http://www.ssc.gov.vn/portal/page/portal/ubck/daugia_dauthau/1228465?p_page_id=1228465&pers_id=1268547&folder_id=&item_id=1517448&p_details=1

Sterner, T. (2003). *Policy instruments for environmental and natural resource management*: Resources for the Future.

Stevenson, M. A., Benard, H., Bolger, P., & Morris, R. S. (2005). Spatial epidemiology of the Asian honey bee mite (Varroa destructor) in the North Island of New Zealand. *Preventive Veterinary Medicine, 71*(3-4), 241-252.

Summerville, K. S., & Crist, T. O. (2001). Effects of experimental habitat fragmentation on patch use by butterflies and skippers (Lepidoptera). *Ecology, 82*(5), 1360-1370.

Sutherland, D., & Ham, S. (1992). Child-to-parent transfer of environmental ideology in Costa Rican families: An ethnographic case study. *Journal of Environmental Education, 23*(3), 9-16.

Swallow, S. K., Talukdar, P., & Wear, D. N. (1997). Spatial and Temporal Specialization in Forest Ecosystem Management under Sole Ownership. *American Journal of Agricultural Economics, 79*(2), 311-326.

Swart, J. (2003). Will Direct Payments Help Biodiversity? *Science, 299*(5615), 1981-1982.

Tahvonen, O. (1999). Forest harvesting decisions: the economics of household forest owners in the presence of in situ benefits. *Biodiversity and Conservation, 8*(1), 101-117.

Tahvonen, O. (2004a). Optimal harvesting of forest age classess: A survey of some recent results *Mathematical Population Studies, 11*(3), 205-232.

Tahvonen, O. (2004b). Timber production versus old-growth preservation with endogenous prices and forest age-classes. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 34*(6), 1296-1310.

Tahvonen, O., & Kallio, M. (2006). Optimal harvesting of forest age classes under price uncertainty and risk aversion. *Natural Resource Modeling, 19*(4), 557-585.

Tahvonen, O., Pukkala, T., Laiho, O., Lähde, E., & Niinimäki, S. (2010). Optimal management of uneven-aged Norway spruce stands. *Forest Ecology and Management, 260*(1), 106-115.

Tamayo, G., Guevara, L., & Gamez, R. (2004). Biodiversity prospecting: the INBio experience. In A. T. Bull (Ed.), *Microbial diversity and bioprospecting* (pp. 445-449). Washington: American Society for Microbiology.

Tavoni, M., Sohngen, B., & Bosetti, V. (2007). Forestry and the carbon market response to stabilize climate. *Energy Policy, 35*(11), 5346-5353.

ten Kate, K., Bishop, J., & Bayon, R. (2004). Biodiversity offsets: Views, experience, and the business case: by: IUCN, Gland, Switzerland and Cambridge, UK and Insight Investment, London, UK.

Termansen, M. (2007). Economies of scale and the optimality of rotational dynamics in forestry. *Environmental & Resource Economics, 37*(4), 643-659.

Thiollay, J. M. (1997). Disturbance, selective logging and bird diversity: a Neotropical forest study. *Biodiversity and Conservation, 6*(8), 1155-1173.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., et al. (2004). Extinction risk from climate change. [Article]. *Nature, 427*(6970), 145-148.

Thompson, M. P., Adams, D., & Sessions, J. (2009). Radiative forcing and the optimal rotation age. *Ecological Economics, 68*(10), 2713-2720.

Thomson, T. A. (1992). Optimal forest rotation when stumpage prices follow a diffusion process *Land Economics, 68*(3), 329-342.

Thornber, K. (1999). *Overview of global trends in FSC certificates*. London, UK: International Institute of Environment and Development.

Tilman, D., & Downing, J. A. (1996). Biodiversity and stability in grasslands. *Nature, 367*, 363-365.

Tilman, D., Naeem, S., Knops, J., Reich, P., Siemann, E., Wedin, D., et al. (1997). Biodiversity and ecosystem properties. *Science, 278*(5345), 1866-1867.

Tisdell, C. (1988). Sustainable development - differing perspectives of ecologists and economist, and relevance to LDCS. *World Development, 16*(3), 373-384.

Toman, M. A. (1994). Economics and sustainability - balancing trade-offs and imperatives. *Land Economics, 70*(4), 399-413.

Tomicevic, J., Shannon, M. A., & Milovanovic, M. (2010). Socio-economic impacts on the attitudes towards conservation of natural resources: Case study from Serbia. *Forest Policy and Economics, 12*(3), 157-162.

Touza, J., Perrings, C., & Chas Amil, M. L. (2009). Harvest Decisions and Spatial Landscape Attributes: The Case of Galician Communal Forests. *Environmental and Resource Economics, 44*(5), 1-17.

Touza, J., Termansen, M., & Perrings, C. (2008). A bioeconomic approach to the Faustmann-Hartmann model: ecological interactions in managed forest *Natural Resource Modeling, 21*(4), 551-581.

TRAFFIC (2009). *Saving Plants that Save Lives and Livelihoods*: WWF Germany and TRAFFIC.

Traill, L. W., Bradshaw, C. J. A., & Brook, B. W. (2007). Minimum viable population size: A meta-analysis of 30 years of published estimates. *Biological Conservation, 139*(1-2), 159-166.

Turner, R. K., & Wibe, S. (1992). *Market and Government failures in environmental management : Wetlands and forests*. Paris: Organization for Economic Cooperation and Development.

UNFCCC About CDM. Retrieved 28/09/2010, from http://cdm.unfccc.int/about/index.html

UNFCCC (1997). *The Kyoto Protocol to UNFCCC*.

UNFCCC (2009). (UN Framework Convention on Climate Change) Copenhagen Accord. Retrieved 28/09/2010, from http://www.denmark.dk/en/menu/Climate-Energy/COP15-Copenhagen-2009/Selected-COP15-news/A+Copenhagen-Accord-it-is.htm

UNFNCCC (2010). UNFCCC receives list of government climate pledges Retrieved 04/10/2010, from http://unfccc.int/files/press/news_room/press_releases_and_advisories/application/pdf/pr_accord_100201.pdf

UNFCCC (2011). "REDD Background." Retrieved 10/06/2011, from http://unfccc.int/methods_science/redd/items/4547.php.

Van Dam, C. (2011). "Indigenous Territories and REDD in Latin America: Opportunity or Threat?" *Forests* **2**(1): 394-414.

van Kooten, G. C. (1998). Economics of conservation biology: a critical review. *Environmental Science and Policy, 1*(1), 13-25.

van Kooten, G. C., Binkley, C. S., & Delcourt, G. (1995). Effect of Carbon Taxes and Subsidies on Optimal Forest Rotation Age and Supply of Carbon Services. *American Journal of Agricultural Economics, 77*(2), 365-374.

Vardas, G., & Xepapadeas, A. (2010). Model Uncertainty, Ambiguity and the Precautionary Principle: Implications for Biodiversity Management. *Environmental and Resource Economics*, 1-26.

Vietnamese Government (1998). Decision of the Prime Minister regarding to the project of five million hectares afforestation, Decision No 661/1998/QD-TTg dated 29 July 1998, Hanoi.

Vietnamese Government (1999). Decree of the Government on allocation of forest lands to households, individuals and organizations for long-term forestry purposes, Decree No 163/1999/QD-CP dated 16 November 1999, Hanoi.

Vietnamese Government (2004). Decree of the Government regarding to bank loans for project, Decree No. 106/2004/ND-CP dated 01 April 2004, Hanoi.

Vietnamese Government (2005a). Decision of Head of Ministry of Agriculture and Rural Development on Regulations on harvesting timber and non-timber products, Desicion No. 40/2005/QD-BNN dated 7 July 2005, Hanoi.

Vietnamese Government (2005b). Decision of the Head of Ministry of Agriculture and Rural Development on costs for forest planting, regeneration and protection, Decision No. 38/2005/QD-BNN, Hanoi.

Vietnamese Government (2005c). Decree of the Government on contracting agricultural lands, productive forest lands, and aquatic lands of state agricultural enterprises and state forest enterprises, Decree No 135/2005/QD-CP dated 08 November 2005, Hanoi.

Vietnamese Government (2005d). Decree of the Government regarding to bank loans for project, Decree No. 20/2005/ND-CP dated 28 February 2005, Hanoi.

Vietnamese Government (2006). Decree of the Government on implementation of the Law of Forest Protection and Development, Decree No 23/2006/QD-CP dated 03 March 2006, Hanoi.

Vietnamese Government (2007a). Decision of the Prime Minister on some policies to develop productive planted forests in the period 2007-2015, Decision No 147/2007/QD-TTg dated 10 September 2007, Hanoi.

Vietnamese Government (2007b). Decision of the Prime Minister on the amendments of some policies regarding Five Million Hectare Program, Decision No 100/2007/QD-TTg dated 06 July 2007, Hanoi.

Vietnamese Government (2007c). Quyet dinh ve mot so co che, chinh sach tai chinh doi voi du an dau tu theo co che phat trien sach (Decisions on mechanisms and policies for CDM projects) No 130/2007/QD-TTg dated 2nd August 2007, Hanoi.

Vietnamese Government (2008). Quyet dinh Chinh sach thi diem chi tra dich vu moi truong rung (Decisions on policies to implement a trial payment for environmental forest services) No 380/2008/QD-TTg dated 10th April 2008, Hanoi.

Vietnamese Government (2009). Decision of the Prime Minister regarding to subsidy interest rate from bank loans for individuals and organizations, Decision No. 443/2009/QD-TTg dated 04 April, Hanoi.

Vila, M., Vayreda, J., Comas, L., Ibanez, J. J., Mata, T., & Obon, B. (2007). Species richness and wood production: a positive association in Mediterranean forests. *Ecology Letters, 10*(3), 241-250.

VNexpress (2006). Vietnam is the most biological diversity countries in the world (Viet Nam co da dang sinh hoc cao nhat the gioi). *http://vnexpress.net/GL/Khoa-hoc/2006/02/3B9E6695/.*

Vo, D. H., Dang, T. T., Nguyen, H. T., Nguyen, V. B., & Dang, T. D. (2009). *Productivity and Carbon Sequestration of Some Major Planted Forest in Vietnam*. Hanoi: Argriculture.

Weitzman, M. L. (2000). Economic Profitability Versus Ecological Entropy. *Quarterly Journal of Economics, 115*(1), 237-263.

Wikipedia (2009). Gaia hypothesis. Retrieved 28/09/2010, from http://en.wikipedia.org/wiki/Gaia_hypothesis

Wilsey, B. J., & Potvin, C. (2000). Biodiversity and ecosystem functioning: importance of species evenness in an old field. *Ecology, 81*(4), 887-892.

Wilson, E. O. (1988). The current state of biological diversity. In E. O. Wilson (Ed.), *Biodiversity* (pp. 3±18). Washington, D.C.: National Academy Press.

Worldbank (2008). World Development Indicators 2007,. Retrieved 04/10/2010, from http://ddp-ext.worldbank.org/ext/ddpreports/ViewSharedReport?&CF=&REPORT_ID=9147&REQUEST_TYPE=VIEWADVANCED&HF=N/CPProfile.asp&WSP=N

Worm, B., Barbier, E. B., Beaumont, N., Duffy, J. E., Folke, C., Halpern, B. S., et al. (2006). Impacts of biodiversity loss on ocean ecosystem services. *Science, 314*(5800), 787-190.

Wunder, S. (2005). *Payments for environmental services: some nuts and bolts*: Center for International Forestry Research, Bogor.

Wunder, S. (2006). Are direct payments for environmental services spelling doom for sustainable forest management in the tropics. *Ecology and Society, 11*(2), 23.

Xuan, H. (2007). Government Bonds. *VNeconomy*. Retrieved 07/09/2010, from http://vneconomy.vn/64969P0C7/lai-suat-trai-phieu-chinh-phu-bat-dau-tang.htm

Yamaura, Y., Ikeno, S., Sano, M., Okabe, K., & Ozaki, K. (2009). Bird responses to broad-leaved forest patch area in a plantation landscape across seasons. *Biological Conservation, 142*(10), 2155-2165.

Yap, C. A. M., Sodhi, N. S., & Peh, K. S. H. (2007). Phenology of tropical birds in Peninsular Malaysia: Effects of selective logging and food resources. *Auk, 124*(3), 945-961.

Yen Bai Forestry Department (2008). *Report on forest status*.

Zhang, D., & Flick, W. A. (2001). Sticks, carrots, and reforestation investment. *Land Economics, 77*(3), 443-456.

Zhou M, Buongiorno J. (2011) Effects of stochastic interest rates in decision making under risk: A Markov decision process model for forest management. *Forest Policy and Economics*.

PERSONAL COMMUNICATION

Forestry Department of Yen Bai province, 2008. Interview with Kieu Tu Giang, Director, Yen Bai, Vietnam (17 May).

Institute of Forest Science, 2008. Interview with Dang Thinh Trieu, Researcher, Hanoi, Vietnam (18 May).

Ministry of Agriculture and Rural Development, 2008. Interview with Dr. Nguyen Nghia Bien, Director of Forestry Department, Hanoi, Vietnam (9 May).

Ministry of Agriculture and Rural Development, 2009. Interview with Dr. Nguyen Nghia Bien, Director of Forestry Department, Hanoi, Vietnam (16 November).

Viet Hung Forestry Company, 2008. Interview with Nguyen Van Hoang, Vice Head, Yen Bai, Vietnam (16 May).

Viet Hung Forestry Company, 2008. Interview with Doan Tat Pha, staff and a household forest owner, Yen Bai, Vietnam (16 May).

Vietnam Forestry University, 2008. Interview with Prof. Nguyen Van Tuan, Vice Rector, Hanoi, Vietnam (10 May).

Vietnam Forestry University, 2008. Email correspondence with Pham Minh Toai, Lecturer, Hanoi, Vietnam (9 February).

Yen Binh Forestry Company, 2008. Interview with Pham Thanh Ky, Head, Yen Bai, Vietnam (16 May).

Note: Personal communications are used for developing questionnaires for the survey in Yen Bai province, Vietnam, and the development of a timber price function.