

## TABLE OF CONTENTS

	Page
<b>ACKNOWLEDGEMENTS</b>	iii
<b>ENGLISH ABSTRACT</b>	iv
<b>THAI ABSTRACT</b>	vi
<b>TABLE OF CONTENTS</b>	viii
<b>LIST OF TABLES</b>	xi
<b>LIST OF FIGURES</b>	xiii
<b>ABBREVIATIONS</b>	xvi
 <b>CHAPTER 1 INTRODUCTION</b>	 <b>1</b>
1.1 Problem	1
1.2 Background	1
1.3 Hypothesis	3
1.4 Objectives	3
 <b>CHAPTER 2 LITERATURE REVIEW</b>	 <b>5</b>
2.1 The Naban River Watershed National Nature Reser	5
2.1.1 Climate	7
2.1.2 Soils	9
2.1.3 Biological Diversity and Ecosystem Services	11
2.1.4 Land Use	12
2.1.5 Demography and Economy	13
2.2 <i>Hevea brasiliensis</i>	15
2.2.1 Cultivation	17
2.2.2 Temperature, Sunlight and Wind	18
2.2.3 Water and Irrigation	19
2.2.4 Soils and Fertilization	21

## TABLE OF CONTENTS (Continued)

2.2.5 Diseases and Pests	23
2.2.6 Tree Spacing and Intercropping	24
2.2.7 Latex Properties and Collection	25
2.2.8 Limiting Factors	26
2.2.9 Current Distribution of Rubber Plantations	27
<b>CHAPTER 3 MATERIALS AND METHODS</b>	<b>29</b>
3.1 The Study Area	29
3.2 Software	29
3.3 Maps	30
3.4 Parameterization of the LUCIA Model	34
3.5 Model Outputs	35
3.6 Calibration of the LUCIA Model	35
<b>CHAPTER 4 RESULTS</b>	<b>37</b>
4.1 Biomass and Carbon Sequestration of Selected Land Uses in the Naban River Watershed National Nature Reserve	37
4.1.1 Rubber	38
4.1.1.2 Xishuangbanna	39
4.1.1.3 Hainan Island	41
4.1.2 Calculation of Rubber Tree Biomass in the Naban River Watershed National Nature Reserve	42
4.1.3 Paddy Rice, Maize, Orchards/tea, Grasslands and Forests	48
4.1.3.1 Paddy Rice, Maize, Orchards/tea and Grasslands	48
4.1.3.2 Primary Tropical Seasonal Rainforests	49
4.1.3.3 Primary Tropical Montane Rainforests and Secondary Tropical Seasonal and Montane Rainforests	50
4.1.3.4 Primary and Secondary Subtropical Evergreen Broadleaf Forests	51

## TABLE OF CONTENTS (Continued)

4.2 Simulated Biomass, Soil Carbon, Soil CO <sub>2</sub> Emissions and Carbon Balance	53
4.2.1 Biomass, Litter Inputs and Carbon Exports	54
4.2.1.1 Biomass	54
4.2.1.2 Litter Inputs and Carbon Exports	58
4.2.2 Soil Carbon	60
4.2.3 Soil Carbon Dioxide Emissions	64
4.2.4 Carbon Balance	67
<b>CHAPTER 5 DISCUSSION</b>	<b>72</b>
<b>CHAPTER 6 CONCLUSIONS</b>	<b>88</b>
<b>REFERENCES</b>	<b>93</b>
<b>APPENDICES</b>	<b>109</b>
<b>APPENDIX A</b>	<b>110</b>
<b>APPENDIX B</b>	<b>114</b>
<b>CURRICULUM VITAE</b>	<b>123</b>

## LIST OF TABLES

Table	Page
1 Phenological stages of mature rubber plantations in Xishuangbanna	17
2 Effect of different irrigation treatments on girth increment, biomass production and tappable trees (January 1994) in rubber in North Konkan, India	20
3 Fertilization of rubber plantations in the NRWNNR	22
4 Application of pesticides in rubber plantations in the NRWNNR	24
5 Share of aboveground and belowground biomass in % of rubber trees of ages 7, 13, 19, 25 and 47 years at low elevations in Xishuangbanna	40
6 Aboveground biomass allocation of 14 year old rubber trees at low, medium and high elevations in Xishuangbanna	41
7 Tree biomass regression models for rubber plantations at low, medium and high elevations in the NRWNNR	43
8 Biomass regression models for rubber plantations (450 trees per ha) at low, medium and high elevations in the NRWNNR	45
9 Biomass estimations of Xishuangbanna's primary tropical seasonal rainforests	50
10 Biomass estimations of Xishuangbanna's primary tropical montane rainforests	50
11 Outputs of the LUCIA model	53
12 Total area in ha by land use in the sub-watershed, 1992 to 2003	55
13 Average yearly expansion rate in ha and % by land use in the sub-watershed, 1992 to 2003	55
14 Biomass in Mg by land use area in the sub-watershed, 1992 and 2003	57
15 Cumulative litter inputs in Mg C by land use area in the sub-watershed, 1992 to 2003	59

16	Cumulative carbon exports in Mg C by land use area in the sub-watershed, 1992 to 2003	60
17	Topsoil carbon contents in Mg C per ha, 1992 and 2003	62
18	Total soil carbon in Mg C by land use area in the sub-watershed, 1992 and 2003	63
19	Mean daily and mean yearly cumulative soil CO <sub>2</sub> emissions in Mg CO <sub>2</sub> per ha, 1993 to 2003	65
20	Yearly soil CO <sub>2</sub> emissions in Mg CO <sub>2</sub> by land use area, 1994 and 2003	66
21	Cumulative soil CO <sub>2</sub> emissions in Mg CO <sub>2</sub> by land use area, 1992 to 2003	66
22	Simulated (sim.) and estimated (est.) yearly cumulative soil CO <sub>2</sub> emissions in Mg CO <sub>2</sub> of the sub-watershed, 1992 to 2003	67
23	Carbon balance in Mg CO <sub>2</sub> per ha of the land uses in the sub-watershed, 1994 and 2001	69
24	Yearly and cumulative carbon balance in Mg CO <sub>2</sub> by land use area in the sub-watershed, 1992 to 2003	70

## LIST OF FIGURES

Figure	Page
1 Location of the NRWNNR	5
2 Zonation and settlements in the NRWNNR	6
3 Chinese price of natural rubber in € per Mg, 1967 to 1990, and world price of natural rubber in € per Mg, 2002 to first half of 2012	7
4 Mean monthly precipitation in mm/month; and mean highest, mean average and mean lowest temperatures in ° C in Jinghong, 1954 to 2007	9
5 Average daily soil and air temperature in ° C and daily precipitation in mm in Jinghong, 2011	10
6 Rubber cover in ha in Xishuangbanna, 1963 to 2010	12
7 Land uses in the NRWNNR, 2006/07	13
8 Rubber plantation in the NRWNNR	15
9 Rubber fruits	16
10 Rubber seeds	16
11 Latex tapping from a rubber tree in the NRWNNR	25
12 Dry latex yield at low, medium and high elevations during the tapping period in Xishuangbanna	26
13 Selected sub-watershed in the NRWNNR	31
14 Elevation map of the sub-watershed	31
15 Cost distance map for the contraction of agricultural land uses from each village centre	32
16 Yearly contraction of agricultural land uses, 2007 to 1992	32
17 Land use map from 1993	33
18 Land use map from 2006/07	33
19 Soil type map	33
20 Local drain direction map	33
21 Biomass in Mg per ha of rubber plantations in western Ghana, Mato Grosso, Xishuangbanna, the NRWNNR, and Hainan Island	40

22	Total, total C, aboveground and belowground biomass in Mg per ha (450 trees per ha) of a 14 year old rubber plantation at low, medium and high elevations in the NRWNNR	44
23	Aboveground (AB) and belowground (BB) biomass in Mg per ha of 0 to 38 year old rubber plantations at low, medium and high elevations in the NRWNNR	46
24	Stem, branch and leaf biomass in Mg per ha of 0 to 38 year old rubber plantations at low and medium elevations in the NRWNNR	47
25	Biomass carbon estimations in Mg C per ha of mature rubber, paddy rice, and primary and secondary forests in Xishuangbanna	52
26	Total area in ha by land use in the sub-watershed, 1992 to 2003	54
27	Biomass in Mg per ha of the sub-watershed's land uses, 1992 to 2003	56
28	Biomass in Mg by land use area in the sub-watershed, 1992 to 2003	57
29	Biomass in Mg by forest type area and sub-watershed, 1992 to 2003	58
30	Litter inputs in Mg C per ha by land use of the sub-watershed, 1992 to 2003	59
31	Carbon exports in Mg C per ha by land use of the sub-watershed, 1992 to 2003	60
32	Carbon in topsoil in Mg C per ha for every land use in the sub-watershed, 1992 to 2003	61
33	Carbon in subsoil in Mg C per ha for every land use in the sub-watershed, 1992 to 2003	62
34	Total soil carbon in Mg C by land use area in the sub-watershed, 1992 to 2003	63
35	Daily soil CO <sub>2</sub> release in Mg CO <sub>2</sub> per ha by land use in the sub-watershed, 1992 to 2003	64
36	Daily soil CO <sub>2</sub> release in Mg CO <sub>2</sub> by land use area in the sub-watershed, 1992 to 2003 I	65
37	Daily soil CO <sub>2</sub> release in Mg CO <sub>2</sub> by land use area in the sub-watershed, 1992 to 2003 II	65
38	Daily soil CO <sub>2</sub> release in Mg CO <sub>2</sub> of the sub-watershed, 1992 to 2003	66



39	Carbon balance in Mg CO <sub>2</sub> per ha of the land uses in the sub-watershed, 1992 to 2003	68
40	Cumulative carbon balance in Mg CO <sub>2</sub> per ha of the land uses in the sub-watershed, 1992 to 2003	69
41	Yearly carbon balance in Mg CO <sub>2</sub> by land use area in the sub-watershed, 1992 to 2003	70
42	Carbon balance in Mg CO <sub>2</sub> of the sub-watershed, 1992 to 2003	71



## ABBREVIATIONS

NRWNNR	Naban River Watershed National Nature Reserve
MMSEA	Mainland Montane South East Asia
LUCIA model	Land Use Change Impact Assessment model
cm <sup>3</sup>	cubic centimetre
km <sup>2</sup>	Square kilometre
ha	hectare
m	metre
cm	centimetre
mm	millimetre
g	gram
kg	kilogram
Mg	mega gram
Mt	mega ton
GBH	girth at breast height
DBH	diameter at breast height
°C	degree centigrade
C	carbon
CO <sub>2</sub>	carbon dioxide
SOC	soil organic carbon
LAI	leaf area index
ET <sub>0</sub>	reference evapotranspiration
LE	low elevation
ME	medium elevation
HE	high elevation
LME	low and medium elevations
LMHE	low, medium and high elevations