TEAK IN MEKONG FOR A SUSTAINABLE FUTURE

Teak (*Tectona grandis*) is one of the most important valuable hardwoods in the world that contributes to national economic growth and livelihood enhancements. Natural teak forests occur in central and southern India, Myanmar, Thailand, and Lao PDR. In addition, teak has been grown across 70 tropical countries. However, natural teak forests are declining in all the native teak growing countries mainly due to over-exploitation and agriculture expansion. This edited book entitled "TEAK IN MEKONG FOR A SUSTAINABLE FUTURE" is the outcomes of the ITTO executed Teak Mekong Project in the Greater Mekong sub-region implemented with the financial support of the Federal Ministry of Food and Agriculture, Government of the Federal Republic of Germany (BMEL) with the participating countries of Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam.

The book comprises six main sections, namely (1) Introduction, (2) Teak distribution across the Greater Mekong Sub-region (3) Silvicultural practices and teak improvement techniques, (4) Sustainable teak forest management and certification, (5) Research in teak genetics, and (6) Policy and regional/international collaboration. It also provides policy recommendations and guidance for future work in promoting sustainable management of natural and planted teak forests in the tropics.

It is hoped that this book will serve not only the larger global teak community with the state of up-to-date information on the conservation of teak genetic resources, but also on the sustainable management and use of legally harvested teakwood from natural and planted teak forests, strengthening the capacity building of smallholder teak communities, legal and sustainable supply chains, and sharing lesson-learned and experiences among multi-stakeholders in the region. The book contributes to the achievement of international conventions and agreements such as UN SDGs, and the Global Forest Goals.

ISBN 978-616-278-693-8
9786162786938

TEAK IN MEKONG FOR A SUSTAINABLE FUTURE

YONGYUT TRISURAT, HWAN-OK MA
TETRA YANUARIADI, PROMODE KANT
AND P.K. THULASIDAS
Editors

Federal Ministry of Food and Agriculture
ITTO
TEAKNET

TEAK IN MEKONG
FOR A SUSTAINABLE FUTURE

YONGYUT TRISURAT, HWAN-OK MA
TETRA YANUARIADI, PROMODE KANT
AND P.K. THULASIDAS
Editors

TEAK IN MEKONG FOR A SUSTAINABLE FUTURE

Outcomes of the BMEL-ITTO Project:
"Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region"

YONGYUT TRISURAT, HWAN-OK MA
TETRA YANUARIADI, PROMODE KANT
AND P.K. THULASIDAS
Editors

2022

KASETSART UNIVERSITY
INTERNATIONAL TROPICAL TIMBER ORGANIZATION
TEAKNET

TEAK IN MEKONG FOR SUSTAINABLE FUTURE

Published by Kasetsart University, International Tropical Timber Organization and TEAKNET

Printing August 2022

Citation KU, ITTO and TEAKNET. 2022. Teak in Mekong for a Sustainable Future. Kasetsart University, Bangkok, Thailand; International Tropical Timber Organization, Yokohama, Japan; and TEAKNET, Kerala, India. 359 p.

ISBN: 978-616-278-693-8

Editors Yongyut Trisurat, Hwan-ok Ma, Tetra Yanuariadi, Promode Kant, and P.K. Thulasidas

Printed by Boonsiri Printing Co., Ltd.
9/11-13 Sena Nikhom 1 Soi 1, Sena Nikhom, Chatuchak, Bangkok 10900
662-941-6650, 668-813-4199

CONTENTS

FOREWORD		xiii
MESSAGE FROM ITTO		xv
MESSAGE FROM BMEL		xvii
ABOUT THE EDITORS		xviii
AUTHORS AND THEIR AFFILIATIONS		xx
PREFACE		xxii
ACKNOWLEDGEMENTS		xxiii
ACRONYMS AND ABBREVIATIONS		xxiv
	SECTION I: INTRODUCTION	1
Chapter 1	Overview and Achievements of the BMEL-ITTO Teak Project in Mekong *Yongyut Trisurat, Nikhom Laemsak, Hwan-ok Ma, Tetra Yanuariadi, Promode Kant and P.K. Thulasidas*	2
	SECTION II: TEAK DISTRIBUTION ACROSS THE GREATER MEKONG SUB-REGION	21
Chapter 2	Teak Management in Thailand *Sapol Boonsermsuk*	22
Chapter 3	Natural Teak Forests and Teak Plantations in Myanmar *Zar Chi Hlaing*	37
Chapter 4	Natural Teak Forests and Plantations in Lao PDR *Vongvilay Vongkhamsao, Baisone Inthirath and Bounthavy Cchaleunsouk*	51
Chapter 5	Teak Plantations in Cambodia *Say Sinly, Chheang Dany, Kim Sobon, Lim Sopheap, Hort Sothea and Pang Phanit*	62
Chapter 6	Teak Plantations in Vietnam *Dang Thinh Trieu, Tran Lam Dong and Nguyen Van Bich*	78
Chapter 7	Mapping of Natural Teak Forests and Teak Plantations in the Greater Mekong Sub-region *Chakrit Na Takuathung*	87
Chapter 8	Climate Change Impact on Natural Teak Forests in the Greater Mekong Sub-region *Yongyut Trisurat, Sapol Boonsermsuk, Vongvilay Vongkhamsao* and *Zar Chi Hlaing*	101

	SECTION III: SILVICULTURAL PRACTICES AND TEAK IMPROVEMENT	117
Chapter 9	Teak Plus Tree Selection and Its Propagation Techniques Used in Thailand *Chumnun Piananurak*	118
Chapter 10	Technique for Controlled Hand-Pollination of Teak (*Tectona grandis* L.f.) *SuwanTangmitcharoen*	130
Chapter 11	Teak-Based Pest and Disease Management in Myanmar *Thant Shin, Zaw Min Aye and Myo Htet Aung*	144
Chapter 12	Insect Pest Management in Teak Plantations in Thailand *Wattanachai Tasen and Decha Wiwatwitaya*	149
Chapter 13	Indonesia's Teak Resources, Breeding and Biotechnology *Anto Rimbawanto and ILG Nurtjahjaningsih*	155
Chapter 14	Effects of First Thinning on Growth and Stem Form of Teak Plantations in Thailand *Tosporn Vacharangkura*	165
Chapter 15	Silviculture Aspects of Large-Scale Teak Plantations in Brazil *Sylvio de Andrade Coutinho and Fausto Hissashi Takizawa*	182
	SECTION IV: SUSTAINABLE TEAK FOREST MANAGEMENT AND CERTIFICATION	201
Chapter 16	Teak Timber Harvesting *Nopparat Kaakkurivaara*	202
Chapter 17	Teak Small Holder Plantations in Indonesia for Improving Livelihood *Anis Fauzi, and Anto Rimbawanto*	212
Chapter 18	Carbon Sequestration and Carbon Credits of Teak Plantations *S. Sankar*	223
Chapter 19	Review of the Current Trade Trends of Tropical Timber and Timber Products *Tetra Yanuariadi and Jean-Christophe Claudon*	232
	SECTION V: RESEARCH IN TEAK GENETICS	244
Chapter 20	Conservation Approaches of Teak Genetic Resources in Thailand *Suwan Tangmitcharoen*	245
Chapter 21	Progress in Teak Improvement Program in Thailand *Chumnun Piananurak*	256
Chapter 22	Clonal Teak for Sustainable Plantation Establishment *Doreen K.S. Goh*	270

SECTION VI: POLICY AND REGIONAL/INTERNATIONAL COLLABORATION 284

Chapter 23 Ensuring Legal and Sustainable Teak Supply Chains in the Lower Mekong Region 285
Hwan-ok Ma

Chapter 24 Forests, Timber Sources and Supply Chains of Myanmar: Opportunities and Constraints to Ensure Legal Origin of Timber 296
Taiji Fujisaki and Barber Cho

Chapter 25 Teak in Mekong: Governance Concerns and The Evolving Policies 315
Promode Kant

Chapter 26 Knowledge Management for Teak: The International Teak Information Network (TEAKNET) 339
P.K. Thulasidas and M.P. Sreelakshmy

Chapter 27 Teak in Mekong for a Sustainable Future: The Way Forward 351
P.K. Thulasidas, Hwan-ok Ma, Tetra Yanuariadi, Yongyut Trisurat and Promode Kant

TABLES

Table 1-1	Demonstration plots established by the ITTO Teak Project in Mekong	11
Table 2-1	Mean annual increment of 50-year rotation of planted teak on the best sites within its natural ranges	28
Table 3-1	Area of major forest types in Myanmar	38
Table 3-2	Forest cover status of Myanmar	39
Table 3-3	Status of reserved forests, protected public forests and protected area system in Myanmar	40
Table 3-4	Teak clonal seed orchard in Myanmar	47
Table 3-5	Seed production areas (SPA) in Myanmar	47
Table 3-6	Teak provenance trials	48
Table 4-1	Types of plantation ownership	56
Table 5-1	Teak plantations in Cambodia	66
Table 5-2	Service fee for timber and non-timber forest products	73
Table 6-3	Growth and productivity of teak plantation in Vietnam.	84
Table 7-1	Definition of data	89
Table 7-2	Area of natural teak forests (1,000 ha) as on 2021	90
Table 7-3	Area of teak plantations (1,000 ha)	90
Table 8-1	Variables and their contributions in the MaxEnt models for teak (*Tectona grandis*)	106
Table 8-2	Estimated extend of occurrence, gain, and loss in the suitable range	107
Table 14-1	Stand characteristics of Den Dan plantation before, just after and 4-year after thinning	169
Table 14-2	Stand volume production (m^3 ha^{-1}) in stands with different thinning intensities	173
Table 14-3	Decrease in annual stand volume increment	175
Table 14-4	Parameters of tree attributes associated with quality of stem form: 4 years after thinning	178
Table 16-1	Reclassification of grading score for each relevant factor.	209
Table 17-1	The population of planted species in the small holder plantation in Indonesia	217
Table 18-1	Carbon content in various compartments of teak	226
Table 18-2	Carbon sequestration in various compartments of teak	226
Table 18-3	Soil carbon stock in 50 year teak plantations	227
Table 18-4	Thinning schedules of teak and trees removed per hectare	227
Table 18-5	Carbon sequestered at various thinning regimes of teak	228
Table 18-6	Carbon sequestration potential of teak plantations in Kerala for the year 2014	228
Table 18-7	Certified Emission Reduction (CER) potential of teak plantations	229

Table 20-1	Teak clonal test planted during 1988-2021 at four regions of Thailand	249
Table 20-2	Progeny test conducted during 2008-2011	251
Table 20-3	Areas of teak seed orchards in Thailand	252
Table 21-1	Information about clone banks in Thailand	259
Table 21-2	Information of CSO in Thailand	264
Table 21-3	Evaluation and genetic thinning plans of teak breeding orchard in each plot (block)	266
Table 23-1	Area certified and number of chain-of-custody certificates issued by the Forest Stewardship Council and the Programme for the Endorsement of Forest Certification in lower-Mekong region.	289
Table 24-4	Measures supporting traceability of legal origin of timber products	299
Table 24-2	Permanent Forest Estate and Protected Areas in Myanmar (December 2019)	300
Table 24-3	Key documents and information included in timber supply chain from log landing to private processing facilities.	309
Table 26-1	Details of membership options	342
Table 26-2	Consulting Services Organized and Implemented by TEAKNET	345

FIGURES

Figure 1-1	Potential suitable habitats at baseline	6
Figure 1-2	Remaining suitable habitats at baseline (masked by land use map)	6
Figure 1-3	Training sessions and number of participants	14
Figure 2-1	Thai provinces with natural teak forests	24
Figure 2-2	Natural teak zonation in Thailand	24
Figure 2-3	Forest area in northern Thailand	26
Figure 2-4	Thailand's wood demand to support national and international market	27
Figure 2-5	Value of import and export of teak logs and sawn-teak timber	31
Figure 2-6	Value of import and export of timbers (all species) and teak	31
Figure 3-1	Major forest types in Myanmar	39
Figure 3-2	Forest cover of Myanmar	40
Figure 3-3	Permanent Forest Estate (PFE) area in Myanmar	41
Figure 3-4	Established Teak plantations area (from 1981 to 2021)	46
Figure 4-1	Map of teak tree seed sources in Lao PDR	53
Figure 4-2	Annual plantation establishment in Lao PDR 1975-2015	55
Figure 4-3	Comparison of planted tree species	55
Figure 5-1	Map showing disperse teak plantations in Cambodia	68
Figure 6-1	Teak seed production plantation established in 1961-1962 in Dong Nai Province	81
Figure 6-2	Teak plants unable to stand straight following removal of *Acacia* hybrid in Thanh Hoa Province	82
Figure 7-1	The general flow chart of the analysis procedure	88
Figure 7-2	The potential natural teak distribution in 2021	90
Figure 7-3	Distribution of teak plantations in Cambodia	92
Figure 7-4	Teak distribution in Lao PDR	94
Figure 7-5	Teak distribution in Thailand	97
Figure 7-6	Teak distribution in Vietnam by zone	98
Figure 8-1	Predicted suitable ecoregions of natural teak and changes in climate space by 2050 and 2070 under RCP6.0 and RCP8.5 scenarios	105
Figure 8-2	Potential suitable habitats at baseline	108
Figure 8-3	Remaining suitable habitats at baseline (masked by land use map)	108
Figure 8-4	Predicted climate change impact on teak distribution by 2050 under CMIP6 scenarios	110
Figure 14-1	Layout of experimental plots	167

Figure 14-2	Mean basal area 4 years after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)	170
Figure 14-3	Mean stem volume 4-year after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq$ 0.05)	170
Figure 14-4	Mean annual DBH increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq$ 0.05)	171
Figure 14-5	Mean annual height increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq$ 0.05)	172
Figure 14-6	Mean stand volume increment. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq$ 0.05)	174
Figure 14-7	Total stand volume production. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq$ 0.05)	174
Figure 14-8	Live-crown ratio and slenderness before and after thinning	176
Figure 14-9	Absolute form factor before and after thinning	177
Figure 15-1	Teak planted area evolution in Brazil	183
Figure 15-2	Operations of the company of the case studied	184
Figure 15-3	Forests and office location of the company of the case studied	185
Figure 15-4	Planted area evolution and history	185
Figure 15-5	Soil water influence depth thematic map	189
Figure 15-6	Soil texture thematic map	189
Figure 15-7	Soil aluminium thematic map	189
Figure 15-8	Growth in individual volume, comparing clone and seed, 17.5 years	191
Figure 15-9	Growth in dbh, comparing clone and seed, 17.5 years	192
Figure 15-10	Activities carried out in the harvest	194
Figure 15-11	Composition of the sawmill	196
Figure 16-1	Example of harvesting plan	203
Figure 16-2	Harvesting process of teak harvesting in Thailand	204

Figure 17-1	Natural distribution of teak	213
Figure 18-1	Teak height varied from 6.93 m at age of five years to 22.83 m at 50 years	225
Figure 18-2	Diameter at breast height also increased with age from 6.36 cm to 45.01 cm from 5th year to 50th year respectively.	226
Figure 19-1	Production of tropical industrial roundwood (logs), 2010-2020, million m^3	236
Figure 19-2	World imports of tropical primary wood products, 1990-2020	236
Figure 19-3	Major trade flows 2020: Tropical logs	237
Figure 19-4	Major importers of tropical sawnwood, 2010-2020	238
Figure 19-5	Major exporters of tropical sawnwood, 2010-2020	238
Figure 19-6	Major Trade Flows 2020: Tropical sawnwood	238
Figure 19-7	Major exporters of tropical plywood, 2010-2020	239
Figure 19-8	Major importers of tropical plywood, 2010-2020	239
Figure 19-9	Major Trade flows 2020: Tropical plywood	240
Figure 19-10	Major tropical exporters of furniture, 2010-2020	241
Figure 19-11	Major trade flows 2020: Wooden furniture from China and ITTO producer countries	241
Figure 20-1	Teak distribution in natural forest in Thailand in protected area and outside	246
Figure 20-2	Teak distribution across different types of protected areas in Thailand	248
Figure 21-1	Teak improvement program in Thailand	257
Figure 21-2	Teak clonal test timeline and the testing information	262
Figure 21-3	Locations of 3 sets of clonal tests of teak plus trees	263
Figure 24-1	AAC and actual harvested teak trees in number	303
Figure 24-2	AAC and actual harvested hardwood in number	303
Figure 24-3	Timber sources and supply chains in Myanmar	306
Figure 24-4	Marks on bucked log	308
Figure 25-1	Sketch map of the existing and proposed forest reserves in Pegu and Tenasserim divisions of British Burmah in 1861. The Karen areas and the boundary of Siam at that time are also shown	318
Figure 26-1	Organigram of TEAKNET	341
Figure 26-2	The Home Page of the TEAKNET Website	343
Figure 26-3	Examples of Publication Media Issued by TEAKNET	344

PHOTOS

Photo 1-1	Launching and 1st PSC meeting, Bangkok on 24 April 2019 (left) and 2nd PSC meeting in Vientiane, Lao PDR on 20 February 2020 (right)	4
Photo 1-2	Teak clonal seed orchard (CSO) in Myanmar (upper left), clonal test in Thailand (upper right), seed orchard (lower left) and tissue culture lab in Thailand (lower right), being maintained under the ITTO Mekong (Teak) Project	9
Photo 1-3	Teak nursery at Kampong Speu demonstration plot, Cambodia (left) and The ITTO Mekong (Teak) Project provides genetically sound teak seedlings to the community (right)	11
Photo 1-4	ITTO Project team visited smallholder teak plantations in Son La province, Viet Nam (left) and Teak smallholders' networking workshop at Ngao Silvicultural Station, Thailand (right)	13
Photo 1-5	Myanmar National Coordinator visited teak planting stock (upper left), Training workshop in Thanh Hoa (upper right), Training on Silviculture techniques (lower left) and Teak improvement technique training, 10-13 July, 14-17 July 2021 at FRI Office and online training to District staff and smallholders, October 2019, Laos (lower right)	14
Photo 1-6	Interview of teak wood trader in Son La Province, Vietnam (left) and VCA Training on 25 February 2022 (right)	15
Photo 1-7	Project provides genetically sound teak seedlings (Myanmar-left) and small fund to community (Thailand-right)	16
Photo 2-1	Nawamintara Rachinee teak forest, Mae Hong Son Province	23
Photo 2-2	A mother teak trees from Paa Sak Nawamindra Rachinee forest, Mae Hong Son Province	29
Photo 2-3	Seedling production from good quality material	29
Photo 2-4	Teak timbers in the log yard at the Forest Industry Organization (FIO)	32
Photo 5-1	Teak plantation with cotton and corn in Han Chey commune, Kampong Cham Province, 1936	64
Photo 5-2	Study visits to private teak plantation in Han Chey commune, Kampong Cham Province and teak nursery at Grandis Timber Limited in Aoral district, Kampong Speu Province	66
Photo 5-3	Measuring and Monitoring of the Target Teak Demonstration Plots belonging to Mr. Keo Kosal, the owner of a private teak plantation in Han Chey commune, Kampong Cham Province	68
Photo 5-4	A study comparing the growth between planting without pruning and maintenance (thinning and pruning) and monitoring the mean annual average growth of teak (mean annual increment-MAI)	69

Photo 5-5	Nursery breeding, experiment in the nursery, using technology (Sensor) to record for monitoring the growth of teak trees at Teak Farm's in Kampong Speu Province	70
Photo 5-6	Teak products--wooden furniture made of teak in Lamphat district, Ratanakiri Province	71
Photo 6-1	Teak seed production plantation established in 1961-1962 in Dong Nai Province	79
Photo 6-2	Teak plants unable to stand straight following removal of Acacia hybrid in Thanh Hoa Province	83
Photo 6-3	Agroforestry model of teak and coffee in Son La Province	83
Photo 7-1	Teak plantations in Cambodia	91
Photo 7-2	Natural teak forest in Xayabuly Province, Lao PDR	93
Photo 7-3	Teak plantations in Luang Prabang Province, Lao PDR	93
Photo 7-4	Natural teak forest in Mae Hong Son Province, Thailand	95
Photo 7-5	Teak plantations in Kanchanaburi Province, Thailand	96
Photo 7-6	70- years old teak plantation in Dak Lak Province, Vietnam	98
Photo 9-1	Plus tree selection	120
Photo 9-2	Teak budding process by patch grafting techniques.	123
Photo 9-3	Rooted cutting processes of teak from rejuvenated materials	124
Photo 9-4	Tissue culture processes of teak	126
Photo 10-1	Inflorescence and flower: Large panicle of teak inflorescence showing high rate of fruit abortion, which commonly occurs in self- and open pollination (left); Teak flowers at receptivity showing six stamens and petals and straight style; and, one day after receptivity after corolla abscised (right)	131
Photo 10-2	Access to flowers of 40 year-old teak using street scaffolds which should be elected soon after emerging of flower bud (July)	134
Photo 10-3	Marking flowers using colored string tied to the pedicel of an unopened flower	137
Photo 10-4	Pollinated flowers are enclosed in a cellophane bag to exclude all potential pollinators	138
Photo 10-5	Controlled pollination by brushing an anther against the stigma of a receptive flower	139
Photo 11-1	Teak plantations damaged by *Eutectona machaeralis* Walker	146
Photo 11-2	Young teak stem and branch damaged by *Xyleutes ceramicus* Walker	146
Photo 11-3	Adult *Eutectona machaeralis* Walker	146
Photo 11-4	Young teak stem and branch damaged by *Xyleutes ceramicus* Walker	147
Photo 11-5	Rust disease	147
Photo 11-6	Teak tree affected by Mistletoe	147
Photo 12-1	Study on teak beehole borer in plantation	151
Photo 12-2	Defoliator damage	153

Photo 13-1	Remnant of century-old teak at Napabalano Nature Reserve in Muna, Southeast Sulawesi	155
Photo 13-2	Clonal plantation of Jati Unggul Nusantara (JUN) 8-years old at Gunung Kidul Yogyakarta	157
Photo 13-3	Flagpole made of teak more than 300 years old and the background board	158
Photo 13-4	Teak stand at Bau Bau, Buton Island	158
Photo 15-1	Superior tree selected for 72 cm dbh at 20 years rotation	186
Photo 15-2	Micro cuttings from genetically superior trees rejuvenated and multiplied	186
Photo 15-3	Pollen collection and controlled pollination in teak	187
Photo 15-4	Mini clonal garden to produce mini cuttings of superior genotypes	187
Photo 15-5	Mini cuttings into tube for rooting	188
Photo 15-6	Greenhouse for rooting mini cuttings	189
Photo 15-7	Seedlings ready for planting in the field	189
Photo 15-8	Old degraded pasture being prepared for teak planting	190
Photo 15-9	Bedding plough with subsoiler	190
Photo 15-10	Teak manual planting with “matraca”	191
Photo 15-11	Teak clonal stand, good and uniform initial growth start	191
Photo 15-12	Chemical weeding in the planting line	192
Photo 15-13	Application of fertilizer in the teak stand	193
Photo 15-14	Pruning with a pole prune saw	193
Photo 15-15	Logs being transported by truck	195
Photo 15-16	Train and wagons transporting teak wood	195
Photo 15-17	Logs being placed inside containers	195
Photo 15-18	A pile of teak logs for export	196
Photo 15-19	Teak wood products	196
Photo 15-20	Macaws in the conservation areas	197
Photo 15-21	Tapirs inside teak stand	197
Photo 15-22	Jaguar family on the side of the road at the teak plantation farm	197
Photo 15-23	Electric pruners of Sunrise Project	198
Photo 15-24	Toque de Letra Project	198
Photo 15-25	Part of the company team during the Internal Work Accident Prevention Week	199
Photo 15-26	Mosaic aerial view of the teak plantation respecting conservation areas	199
Photo 15-27	Teak trees into stand	199
Photo 16-1	Tree felling with chainsaw	205
Photo 16-2	Timber extraction	206
Photo 16-3	Examples of short distance transportation vehicles	206

Photo 16-4	Log processing	207
Photo 16-5	Personal Protective Equipment (PPE)	208
Photo 17-1	Intercropping of maize in teak plantation on Java	214
Photo 17-2	Patterns of agroforestry in a small holder plantation in Nglanggeran, Gunung Kidul	215
Photo 17-3	Teak small holder plantations in Muna, South-east Sulawesi	216
Photo 17-4	An 8-year-old plantation of JUN at Gunung Kidul Yogyakarta	219
Photo 20-1	Nawawintara Rachinee teak forest in Mae Hong Son Province spread over 9,600 ha	247
Photo 20-2	Hauy Tak Teak Biosphere Reserve in Lampang Province	248
Photo 20-3	Clone bank at Ngao SRS with collection of 396 clones over 5.76 ha (left) and Maegar SRS with collection of 113 clones over 0.5 ha (right)	249
Photo 20-4	Clonal test plots Ngao SRS in the North (left) and Thongphapoom SRS in Central Thailand (right)	250
Photo 20-5	Seed orchards at Donglan SRS in Khonkaen Province (left) and at Mae gar SRS in Phayao Province (right)	252
Photo 21-1	Clone bank at Maegar SRS	260
Photo 21-2	Performance of 8 year-old teak trees in half-sib progeny test plots at a) Bantakhun SRS, b) Donglan SRS, and c) Inthakhin SRS	267
Photo 22-1	Herbaceous shoots are collected for in vitro culture from standing mother trees selected based on outstanding morphological traits	272
Photo 22-2	Contamination-free and responsive nodal explants giving rise to axillary microshoots that will be used for subsequent multiplication under optimal tissue culture conditions	273
Photo 22-3	Mass production of clonal teak at the tissue culture facility of YSG Bioscape in Sabah, Malaysia	274
Photo 22-4	Monospecific teak plantation establishment using clonal planting materials with stringent and systematic management practices in Brazil	277
Photo 22-5	Planting of clonal teak along oil palm plantations in Sabah is encouraged for optimizing land use for a dual return that can coincide for both species at the end of the rotation cycle	278
Photo 22-6	Fruits are annually collected from standing mother trees with known origins from one of the two Progeny/Provenance Plot established in 1998 in Sabah, Malaysia	279
Photo 25-1	Teak Plus Tree T6 at Karulai in Nilambur South Forest division, Kerala, India for producing high quality planting stock	328
Photo 25-2	Natural teak forests at Sungam, Parambikulam, Kerala, India	333
Photo 26-1	Visiting Scientists of RITF to teak plantations in Kerala	345
Photo 26-2	Participants at the Bangkok Workshop	347
Photo 26-3	Panelists answering queries from audience	348

FOREWORD

On behalf of Kasetsart University, I would like to express my sincere gratitude and appreciation to the International Tropical Timber Organization (ITTO) and the Ministry of Food and Agriculture of the Federal Republic of Germany (BMEL) for providing this opportunity to Kasetsart University to coordinate the implementation of the project entitled ***Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region (ITTO Teak Project in Mekong)*** in the five participating countries, namely Cambodia, Lao PDR, Myanmar, Thailand and Vietnam.

Natural teak forests occur in India, Myanmar, Thailand, and the Lao PDR. Thailand's natural teak forests are located in the northwestern part of the country and ranks second in area after Myanmar. Historically, to generate income, Thailand granted logging concessions in its teak forests to foreign powers, from around 1829 until the country enforced a logging ban in 1989. Commercial teak plantations have flourished in the period since logging was restricted (about 40 years) which has helped to replace the lost natural teak and met demands for timber in domestic and international markets. The University acknowledges the significance of the research undertaken by this project and the importance of the contributions that the outcomes provide, promoting the socio-economic of local livelihoods in Thailand and the Greater Mekong Sub-region (GMS).

Kasetsart means "**agriculture**. The university was first chartered in 1943 with a mission to provide ***Knowledge of the Land and Natural Resources.*** From its earliest days and continuing now nearly 80 years, KU has promoted educational programs and research that has focused on sustainable development to improve the well-being of Thai society and throughout the GMS. The Faculty of Forestry offers undergraduate, post-graduate, and doctoral degree programs in diverse fields related to sustainable forest management and biodiversity conservation and has gained a world-wide reputation. Based on its consistent record of research and academic excellence, for more than 10 consecutive years KU has ranked within the top 5 universities in Asia and within the top 50 in the world in the QS World University Rankings in fields of Agriculture and Forestry.

The publication of the edited book, ***Teak in Mekong for a Sustainable Future****,* comes at the right time. The book effectively supports implementation of Thailand's governmental policies advancing the country's economic development towards a "value-based economy" and it contributes to various international agreements such as the UN Convention on Biological Diversity (CBD) and its Post-2020 Global Biodiversity Framework, the UN Sustainable Development Goals 2030, the UN Global Forest Goals 2030, and the Paris Climate Agreement. Notably, Article 7 of the amended Forest Act 2019 exempts teak planted on land that is owned or possessed by rights granted under the Thai Code of Land Law. This policy encourages and incentivizes local people to grow more trees, especially teak, which provides greater economic value to the timber trade and increases the density of areas with green cover.

This book contains technical data and information that greatly contributes to the base of knowledge needed by the global teak community. It provides up-to-date information regarding the conservation of teak genetic resources, sets forth best practices for sustainable forest management, and recommendations concerning the use of legally harvested teakwood from natural and planted teak forests. On behalf of Kasetsart University, I extend an invitation to scientists, policymakers, smallholders, and individuals in related commercial sectors in

Thailand and other countries to not only explore the concepts and lessons learned from the research completed by the five participating countries and presented in this book, but to also contribute their own experiences and insights in continuing dialogues.

Finally, I take this opportunity to congratulate the editors and authors who contributed to this comprehensive book.

Dr. Chongrak Wachrinrat
President of Kasetsart University
Bangkok, Thailand

MESSAGE FROM ITTO

For more than three decades, ITTO has been assisting its tropical member countries in their efforts to manage forests sustainably. To this end, the Organization promotes timber production from legal and sustainable sources that simultaneously maintains the ecological values, productivity, resilience and natural regeneration capacity of tropical forests and the cultures and livelihoods of forest-dependent communities.

As part of its work, ITTO is piloting the Legal and Sustainable Supply Chains Programme to encourage the establishment of and best practices on legal and sustainable supply chains in productive tropical forest landscapes. Such supply chains minimize the negative environmental impacts on forests, biodiversity and the environment while respecting the customary user rights of Indigenous Peoples and local communities while enriching livelihoods, enhancing gender equity, health and safety and encourages inclusive participation.

Natural teak forests cover about 29 million hectares in central and southern India, the Lao People's Democratic Republic (Lao PDR), Myanmar and Thailand. These forests play crucial roles in the livelihoods, economies and environment of the Greater Mekong Subregion. Teakwood is recognized as one of the world's most sought after and valuable hardwoods, and it has long been used for a range of products in furniture manufacturing, the ship-building industry and construction. Legal and sustainable teakwood supply chains—from the tree in the forest to shelves in the marketplace can bridge the transition towards a circular bioeconomy. Conversely, illegality and overexploitation can cause the degradation and loss of teak forests in countries that lack the necessary legal and institutional frameworks to counter the immense force of illegal activities across borders.

I am delighted that the Federal Ministry of Food and Agriculture of the Government of the Federal Republic of Germany (BMEL), established a partnership with ITTO to improve the conservation and sustainable management of teak forests and legal and sustainable teakwood supply chains in the Mekong subregion. I am deeply grateful to BMEL for their support in facilitating the capacity building of institutions within and outside governments in the subregion to promote the sustainable management of teak forests and create transparent teakwood supply chains between smallholders, processors and consumers.

I also highly appreciate the collective efforts of the implementing teams in the Mekong region - the Cambodia Forestry Administration, the Lao PDR National Agriculture and Forestry Research Institute, Myanmar's Forestry Department and Forest Research Institute, Thailand's Royal Forest Department and Kasetsart University, and the Vietnamese Academy of Forest Sciences—for their valuable contributions to the BMEL-supported teak partnership.

This report, written by teak experts with extensive on-the-ground experience, showcases best practices in planting, managing, harvesting and processing teak into valuable products and demonstrating legality and sustainability along supply chains. I thank the authors for their dedication in producing this valuable report.

In collaboration with its partners and stakeholders, ITTO will continue promoting sustainable timber production and consumption practices to enable countries and businesses to meet their needs while contributing positively towards achieving the Sustainable Development Goals and the Global Forest Goals.

Sheam Satkuru
ITTO Executive Director
Yokohama, Japan

MESSAGE FROM BMEL

The conservation, restoration and sustainable management of forests is a core objective of the international community in the framework of the United Nations 2030 Agenda for Sustainable Development with its 17 Sustainable Development Goals, especially Goal 15, as well as the United Nations Strategic Plan for Forests 2017–2030 and its Global Forest Goals and targets.

As part of efforts to promote cooperation, coordination, coherence, synergies and political commitment and actions at all levels in achieving these objectives, a partnership between the Federal Ministry of Food and Agriculture of the Government of the Federal Republic of Germany (BMEL) and ITTO has been established for the project "Enhancing the conservation and sustainable management of teak forests and legal and sustainable wood supply chains in the Greater Mekong Subregion". It is the region where teak naturally occurs and originates and I appreciate that countries of the region did not hesitate to support a collective regional or cross-border effort for this project under ITTO.

Teak wood and teak products are characterised by their beauty and unique durability, and they can store carbon for decades and even centuries. Due to ongoing unsustainable and illegal exploitation teak as a species today is endangered and the potential it is offering is at risk. The sustainable and legal production and consumption of teakwood has strong potential to contribute to the livelihoods of local communities and the economic development of the subregion and at the same time to climate-change mitigation and adaption as well as biodiversity conservation. Enhancing legal and sustainable teakwood supply chains can advance a circular bioeconomy in the subregion.

I acknowledge the engagement and hard work of the ITTO project teams in Cambodia, the Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam for the effective implementation of many activities despite the challenges imposed by the COVID-19 pandemic for more than two years. Much more work lies ahead before it can be said with certainty that teak forests in this region are being sustainably managed. I hope this report will serve as a useful reference for policymakers and practitioners here and worldwide in conserving teak as a wonderful species and a precious natural resource.

Matthias Schwörer
Head of Division, International Forest Policy Division
Federal Ministry of Food and Agriculture (BMEL), Germany

ABOUT THE EDITORS

Prof. Dr. Yongyut Trisurat is Professor of Forestry at Kasetsart University in Bangkok, Thailand. He has been active in the area of protected areas, biodiversity conservation, landscape ecology, climate change and GIS for over 25 years and has been a frequent contributor to several international agencies (e.g., ADB, CIDA, DANIDA, FAO, GIZ, IPCC, IPBES, ITTO, IUCN,). Professor Yongyut Trisurat is now a member of Thailand's National Committee for the Conservation and Sustainable Use of Biodiversity, a member of Thailand's National World Heritage Committee, a Co-chair of the Asia-Pacific Biodiversity Observation Network (APBON), Chair of Scientific Committee for ILTER-EAP and the KBA Community representative for East-Asia Region. In addition, he was awarded as Research Fellow/Visiting Professor at several research institutions and universities (e.g., Freie University Berlin, Gottingen University, University of Hawaii and the East-West Center, Turku University, University of Leeds). Professor Yongyut Trisurat has published more than 50 peer-reviewed research articles in international journals, books and book chapters, and presented papers in many international conferences.

Dr. Hwan-ok Ma is a Senior Project Manager at the International Tropical Timber Organization (ITTO), an intergovernmental organization based in Yokohama, Japan, that has promoted sustainable forest management (SFM) in the tropics for more than 30 years. He has followed the capacity building programs of SFM, forest-based climate change adaptation and mitigation, including REDD+, and conservation and sustainable use of biodiversity in tropical production forests, particularly in the Asia-Pacific region. His recent work includes facilitating the preparation of ITTO's guidelines for forest landscape restoration in the tropics, as well as legal and sustainable teakwood supply chains in the Lower Mekong region. He used to be an adjunct professor at the Asian Institute of Technology and is currently an honorary professor at the Myanmar University of Forestry and Environmental Sciences. After studying in forestry at the Korea University, he received a master's degree in forest product marketing and PhD in forest resource economics from the University of Washington, Seattle, USA.

Dr Promode Kant holds a PhD in Climate Change and Forestry, Masters in Physics and Masters in Forestry, and a post graduate diploma in wildlife conservation and management. He has 32 years long experience in the Indian Forest Service related to forest and wildlife management, coastal zone and wetland conservation, forest-tribe interface, international environmental conventions, and corporate management of tea plantations and factories. Between 1997 to 2002 he was responsible for steering the north-eastern tribal communities towards increased sustainability of forests under their control and better management of non-timber forest products. Dr Kant is a frequent visiting faculty at the Indira Gandhi National Forest Academy, Dehradun, and at the Indian Institute of Forest Management, Bhopal. He has written more than 50 papers and has been a co-author of a number of books. He is a regular reviewer of the Elsevier Journal of Energy Policy and of Forest Policy and Economics.

Dr. P.K. Thulasidas holds PhD in Wood Science & Technology from the Forest Research Institute, Dehra Dun, India. He was the Former Senior Scientist & Head, Wood Science and Technology Division of Kerala Forest Research Institute, India and the Former TEAKNET Coordinator of FAO established International Teak Information Network. He is the Dy. Coordinator of IUFRO Teakwood Working Party (Div5.06.02) who organized many Partner Events and Side Events on Teak in different countries across the globe with the involvement of FAO, ITTO and other regional and international agencies. Dr. Thulasidas is currently serving as International Consultant for knowledge management and networking of teak for the ITTO Teak Project now under implementation in Mekong sub-region and is the Chief Editor of Teak Mekong Newsletter and Associate Editor of TEAKNET Bulletin. He also served as editorial board member of the International Journal of Bamboo and Rattan for almost 13 years. He has more than 36 years' vast experience in tropical forestry with profound interest in the wood quality assessment of teak and other tropical timbers, wood anatomy and wood identification, durability studies, quality assessment and physico-chemical characterization of non-timber forest products like rattans and reed bamboos, tree-rings and dendroecological studies of teak etc. He has more than 60 research papers to his credit published in refereed journals besides project reports, handbooks, consultancy reports and presented papers in many international conferences.

Dr. Tetra Yanuriadi is the ITTO Projects Manager of Trade and Industry (since 2008) where goals include enhancing SFM in the tropics while expanding and diversifying the trade in tropical wood products from sustainably managed and legally harvested forests. Objectives are to grow financial/policy support for the implementation of SFM in the tropics, address market access/customs regulations and international policies for tropical forest products and identify measures to implement and balance sustainable production/consumption in line with the SDGs 2030.Tetra was previously the Head of Forestry Division/Forestry Attaché of the Indonesian Embassy, Tokyo (2007); Forest Program Coordinator of WWF Indonesia (2005-2006), and Head of Evaluation Division of the Indonesian Ministry of Forestry and Environment (2001-2005). He graduated from Forestry Faculty of Mulawarman University, Indonesia (1985) and holds a Master degree in Forest Science from ITC-Twente University (1991) and a PhD degree in Agricultural and Environmental Sciences from Wageningen University, the Netherlands (1999).

AUTHORS AND THEIR AFFILIATIONS

Name	Affiliation	Email
Jean-Christophe Claudon	International Tropical Timber Organization (ITTO), Japan	itto-stat@itto.int
Hwan-ok Ma	International Tropical Timber Organization (ITTO), Japan	ma@itto.int
Tetra Yanuariadi	International Tropical Timber Organization (ITTO), Japan	tetra@itto.int
Nopparat Kaakkurivaara	Faculty of Forestry, Kasetsart University, Thailand	ffornrm@ku.ac.th
Nikhom Laemsak	Faculty of Forestry, Kasetsart University, Thailand	ffornil@ku.ac.th
Chakrit Na Takuathung	Faculty of Forestry, Kasetsart University, Thailand	chakrit_n@ku.ac.th
WattanachaiTasen	Faculty of Forestry, Kasetsart University, Thailand	fforwct@ku.ac.th
Yongyut Trisurat	Faculty of Forestry, Kasetsart University, Thailand	fforyyt@ku.ac.th
Decha Wiwatwitaya	Faculty of Forestry, Kasetsart University, Thailand	ffordew@ku.ac.th
Sylvio de Andrade Coutinho	Teak Resources Company (TRC), Brazil	sylvio@teakrc.com
Fausto Hissashi Takizawa	Teak Resources Company (TRC), Brazil	faustot@teakrc.com
Chheang Dany	Forest Administration (FA), Cambodia	wpo@online.com.kh
Pang Phanit	Forest Administration (FA), Cambodia	pangphanit@yahoo.com
Say Sinly	Forest Administration (FA), Cambodia	saysinlyrua@gmail.com
Hort Sothea	Forest Administration (FA), Cambodia	sotheahort@gmail.com
Kim Sobon	Forest Administration (FA), Cambodia	sobonit@yahoo.com
Lim Sopheap	Forest Administration (FA), Cambodia	sopheap73@yahoo.com
Promode Kant	Institute of Green Economy, India	promodekant@gmail.com
S. Sankar	Kerala Forest Research Institute, India	dr.s.sankae@gmail.com
P.K. Thulasidas	TEAKNET, India	thulasidas.teak@gmail.com
M.K. Sreelakshmy	TEAKNET, India	secretariat@teaknet.org
Anis Fauzi	Centre for Forest Biotechnology and Tree Improvement, Indonesia	giant_anies@yahoo.com
ILG Nurtjahjaningsih	Centre for Forest Biotechnology and Tree Improvement, Indonesia	iluh_nc@yahoo.com
Anto Rimbawanto	Centre for Forest Biotechnology and Tree Improvement, Indonesia	rimba@indo.net.id
Taiji Fujisaki	Institute for Global Environmental Strategies (IGES), Japan	fujisaki@iges.or.jp

Bounthavy Cchaleunsouk	National Agriculture and Forestry Research Institute (NAFRI), Lao PDR	Bounthavy99@hotmail.co.th
Baisone Inthirath	National Agriculture and Forestry Research Institute (NAFRI), Lao PDR	sone.be2019@gmail.com
Vongvilay Vongkhamsao	National Agriculture and Forestry Research Institute (NAFRI), Lao PDR	vongvilay7566@gmail.com
Doreen KS Goh	YSG Bioscape Sdn Bhd., Sabah, Malaysia	dorngoh@gmail.com
Zaw Min Aye	Forest Research Institute (FRI), Forest Department, Myanmar	zawminaye@gmail.com
Myo Htet Aung	Forest Research Institute, (FRI) Forest Department, Myanmar	myohteaung@gmail.com
Zar Chi Hlaing	Forest Research Institute (FRI), Forest Department, Myanmar	zarchihlaing08@gmail.com
Thant Shin	Forest Research Institute (FRI), Forest Department, Myanmar	thantshin@gmail.com
Barber Cho	Myanmar Forest Certification Committee (MFCC), Myanmar	secretary@myanmarforestcertification.org
Sapol Boonsermsuk	Royal Forest Department (RFD), Thailand	sapolboonsermsuk@gmail.com
SuwanTangmitcharoen	Royal Forest Department (RFD), Thailand	suwantang@hotmail.com
Chumnun Piananurak	Project's consultant (Thailand)	chumnunpian@gmail.com
Tosporn Vacharangkura	Project's consultant (Thailand)	vtosporn@gmail.com
Nguyen Van Bich	Vietnamese Academy of Forest Sciences (VAFS), Vietnam	bichnv.fsiv@gmail.com
Tran Lam Dong	Vietnamese Academy of Forest Sciences (VAFS), Vietnam	tranlamdong@gmail.com
Dang Thinh Trieu	Vietnamese Academy of Forest Sciences (VAFS), Vietnam	thinhtrieu@hotmail.com

PREFACE

Teak (*Tectona grandis*) is one of the most valuable tropical hardwoods of the world. Natural teak forests occur in India, Myanmar, Thailand and Lao PDR. Teak has been grown increasingly in planted forests in about 70 tropical countries in Africa, Asia-Pacific and Latin America. Natural teak forests, in particular old-growth high quality stands are declining in all the native teak growing countries mainly due to over exploitation, agriculture expansion, shifting cultivation, conversion to other land-uses and growing competition for environmental services.

The ITTO teak project entitled "**Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region (PP-A/54-331)"** aims to promote the sustainable management of natural and planted teak forests with establishment of demonstration plots for conservation of genetic resources and capacity building of key stakeholders in the Mekong sub-region to improve legal and sustainable supply chains for sustainable production and consumption.

This comprehensive book entitled "**Teak in Mekong for a Sustainable Future**" is the outcome of the ITTO teak project in the Greater Mekong Sub-region implemented in the five participating countries of Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam during 2019-2022. The book comprises 27 chapters in 7 main sections, namely (1) Introduction, (2) Teak distribution across the Greater Mekong Sub-region (3) Silvicultural practices and teak improvement techniques, (4) Sustainable teak forest management and certification, (5) Research in teak genetics, and (6) Policy and regional/international collaboration. It also provides policy recommendations and guidance for future work in promoting sustainable management of natural and planted teak forests in the tropics.

It is hoped that this book will serve the global teak community not only with the most up-to-date information on the conservation of teak genetic resources, but also on the sustainable management natural and planted teak forests and sustainable consumption of legally harvested teakwood from sustainable sources. It also intends to promote sustainable investments in teak forests to strengthen capacity building of smallholder teak communities, legal and sustainable supply chains, and multi-stakeholder fora in the region. The book contributes to the achievement of SDGs, especially SDG 1 (No poverty), SDG 12 (Sustainable production and consumption), SDG 13 (Climate action) and SDG 15 (Life on land) and the Global Forest Goals of the United Nations Strategic Plan for Forests 2030 (UNSPF).

ACKNOWLEDGEMENTS

This publication presents the outcome of the ITTO teak project in the Greater Mekong sub-region implemented in Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam during 2019-2022. Publication of this book was made possible by the financial support from the Ministry of Food and Agriculture of the Federal Republic of Germany (BMEL). International Tropical Timber Organization (ITTO) as the executing agency, worked closely with Lao PD's National Agriculture and Forestry Research Institute (NAFRI), Cambodia's Forest Administration (FA), Myanmar's Forest Department, Thailand's Royal Forest Department (RFD), and Vietnam's Vietnamese Academy of Forest Sciences (VAFS). The five participating countries have shown great dedication to promote the sustainable management of teak forests through the legal and sustainable supply chains for sustainable production and consumption and to conserve teak genetic resources.

We gratefully acknowledge the technical cooperation and management provided by the Faculty of Forestry, Kasetsart University and Forest Industry Organization in Thailand; Teak Farm in Cambodia; TEAKNET based in Kerala Forest Research Institute in India; Centre for Forest Biotechnology and Tree Improvement in Indonesia; Asian Forest Cooperation Organization (AFoCO) in Republic of Korea; YSG Bioscape Sdn Bhd in Malaysia; Institute for Global Environmental Strategies (IGES) and JICA in Japan and the Teak Resources Company (TRC) in Brazil for successfully implementing the project in Mekong sub-region. We are thankful to the International Tropical Timber Organization (ITTO) for the fruitful technical support and administrative assistance throughout the project period for implementation.

The editors would like to acknowledge the contribution of the Project Steering Committee, Technical Committee, and Demonstration Plots Selection Committees in Thailand and Cambodia for proving guidance and technical support to fruitily implement the project. Our sincere thanks to all the contributing authors for their high-quality manuscripts and subsequent reviews suggested by the editors. We are grateful to the project staff, Ms. Suchanart Suyarat and Ms. Saichon Mutarapat, to document and formatted various permutations. Valuable comments are provided by Ramon Carrillo during the final stage of printing. Special thanks to Mr. Stephan Wagner and Ms. Silke Hertrich for their constant support. We would especially like to thank Dr. Chongrak Wachrinrat, President of Kasetsart University, Ms. Sheam Satkuru, Executive Director of ITTO, and Mr. Matthias Schwörer, the representative from BMEL for contributing the remarkable foreword and messages for this book.

Yongyut Trisurat, Hwan-ok Ma
Tetra Yanuariadi, Promode Kant
and **P.K. Thulasidas**
Editors

ACRONYMS AND ABBREVIATIONS

AFoCO	Asian Forest Cooperation Organization
AFTSC	ASEAN Forest Tree Seed Centre
B.C.	Before Christ
B.E.	Buddhist Era
BAP	Benzene Adenine Purine
BMEL	Federal Ministry for Food and Agriculture
CBD	Community-based Development
CF	Community Forestry
CFC	Community Forest Conservation
CFE	Community Forest Enterprise
CFI	Community Forestry Instructions
CFU	Community Forestry Units
CFNWG	Community Forestry National Working Group
C&I	Criteria and Indicators
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMIP	Coupled Model Intercomparison Project
CoC	Chains of Custody
CSO	Clonal Seed Orchard
DANIDA	Danish International Development Agency
dbh	Diameter at Breast Height
DNA	Deoxyribonucleic Acid
DNP	Department of National Parks, Wildlife and Plant Conservation, Thailand
FA	Forest Administration, Cambodia
FAO	Food and Agriculture Organization of the United Nations
FD	Forest Department, Myanmar
FIO	Forest Industry Organization, Thailand
FLEGT	Forest Law Enforcement, Governance and Trade
FLR	Forest and Landscape Restoration
FSC	Forest Stewardship Council
GDP	Gross Domestic Products
GHGs	Greenhouse Gases
GIS	Geographic Information Systems
GIZ	German International Cooperation
GMS	Greater Mekong Sub-region
IRR	Internal Rate of Return
IBA	Indole Butyric Acid

ISSR	Inter simple sequence repeats
ITTO	International Tropical Timber Organization
IUCN	International Union for Conservation of Nature
IUFRO	International Union of Forest Research Organization
JIRCAS	Japan International Research Centre for Agricultural Sciences
KU	Kasetsart University
LDD	Land Development Department, Thailand
LMB	Lower Mekong Basin
LPTP	Luang Prabang Teak Programme
MAFF	Ministry of Agriculture, Forestry and Fisheries
MAI	Mean Annual Increment
MFCC	Myanmar Forest Certification Committee
Mha	Million hectares
MIG-seq	Multiplexed ISSR genotyping by sequencing
MMSS	Modified Myanmar Selection System
MOFCOM	Ministry of Commerce of China PR
MRRP	Myanmar Reforestation and Rehabilitation Projects
MSS	Myanmar Selection System
MTE	Myanmar Timber Enterprise
MTLAS	Myanmar Timber Legality Assurance System
NAA	Naphthalene acetic acid
NAFRI	National Agriculture and Forestry Research Institute, Laos
NDCs	Nationally Determined Contributions
NGOs	Non-governmental organizations
NTFPs	Non-timber Forest Products
PAs	Protected Areas
PCR	Polymerase Chain Reaction
PEFC	Program for the Endorsement of Forest Certification
PEPC	Private Forest Plantation Cooperatives
PPE	Personal Protective Equipment
PES	Payment for Ecosystem Services
RCP	Representative Concentration Pathways
RECOFT	Centre for People and Forests (previous name – The Regional Community Forest Training Center for Asia and the Pacific)
REDD	Reducing Emissions from Deforestation and Forest Degradation
RFD	Royal Forest Department, Thailand
SDG	Sustainable Development Goal
SFM	Sustainable Forest Management
SNP	Single-nucleotide polymorphism
SRS	Silvicultural Research Stations
SSO	Seedling seed orchard

SSP	Shared socioeconomic pathways
TEAKNET	International Teak Information Network
TPC	Thai Plywood Company
UN	United Nations
UNSPF	Global Forest Goals of the United Nations Strategic Plan for Forests
VAFS	Vietnamese Academy of Forest Sciences
VCA	Value Chains Analysis
WTC	World Teak Conference

SECTION I
INTRODUCTION

Chapter 1: Overview and Achievements of the BMEL-ITTO Teak Project in Mekong

Yongyut Trisurat, Nikhom Laemsak. Hwan-ok Ma, TetraYanuariadi, Promode Kant and P.K. Thulasidas

Abstract

The ITTO Teak Mekong project "Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region (PP-A/54-331)" is implemented by ITTO with participation of five countries, namely Cambodia, Lao PDR, Myanmar, Thailand and Vietnam as well as with the support of the Kasetsart University of Thailand. The project duration covers 3 years from January 2019 to September 2022.The teak project in Mekong is aimed at assisting governments, local communities and smallholders to enhance natural teak forest management, production and marketing to facilitate the establishment of legal and sustainable wood supply chains while improving national economy and livelihood enhancement of local communities in the GMS. Three outputs and various activities involving the conservation of teak genetic resources, strengthening community-based smallholders teak forest management with improved legal and sustainable supply chains, and regional and international collaboration and information sharing were planned and implemented.

Since February 2020, the COVID-19 pandemic and resultant lockdown disrupted physical meetings, field visits and travels. Field activities, training, and dissemination of information and knowledge sharing were resumed after travel restrictions have been lifted. Monthly webinars and online training programs were also conducted. As of March 2022, there were 21 training courses conducted with more than 750 participants. Fourteen demonstration plots were established in the five participating countries to support community-based smallholders teak forests. Besides, several clonal test and seed production plots were established and good quality seedlings were distributed to teak smallholders. With the support of TEAKNET, 18 issues of bi-monthly electronic newsletter, which carries success stories and support sharing lessons of the project results were widely circulated online to the global teak community including the social media platform of Youtube and Facebook page. The success lessons of the project were also presented at the Regional Teak Workshops, the XV World Forestry Congress and will be presented at the 4th World Teak Conference. Furthermore, this book documented theories and good practices of sustainable forest management of natural and planted teak forests in the Mekong region not merely limited to the five participating countries.

Project Overview

Teak (*Tectona grandis*) is one of the most important valuable tropical hardwoods in the world. It has been used for many centuries for the manufacture of wide range of products in furniture making, ship building, house construction besides providing cultural services. Natural teak forests occur in central and southern India, Myanmar, Thailand and Lao PDR. Considering its prominent position in the global timber market and its potential to contributing to national economies and livelihood enhancement of smallholder communities, teak has been grown increasingly in planted forests in about 70 tropical countries. Natural teak forest area has declined substantially in all native teak growing countries mainly due to overexploitation, agriculture expansion and shifting cultivation. Furthermore, teak seedlings for commercial plantations are established largely from seeds of unknown origin. Thus, there is a high risk of losing their diversity of genetic traits and wood characteristics.

At the 53rd International Timber Council Meeting in Lima, Peru, the ITTO Council approved an activity entitled "*Enhancing Teak Management*" which proposed a comprehensive global activity to improve the management and marketing of both natural and planted teak in all three tropical regions. Also at ITTC 53, the Federal Ministry of Food and Agriculture, Government of the Federal Republic of Germany (BMEL) pledged funds to implement the first stage of this activity in the Greater Mekong Sub-region. The Teak Mekong project "**Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region (PP-A/54-331)"** is aimed at assisting governments, local communities and smallholders to enhance natural and planted teak forest management, production and marketing to facilitate the establishment of legal and sustainable wood supply chains while improving national economy and smallholder communities' livelihood in the Greater Mekong Sub-region (GMS).

This project is being executed by ITTO with the participating institutions in five GMS countries, namely Cambodia's Forestry Administration (FA), Lao PDR's National Agriculture and Forestry Research Institute (NAFRI), Myanmar's Forestry Department, Thailand's Royal Forestry Department (RFD)/Forest Industry Organization and Vietnam's Vietnamese Academy of Forest Sciences (VAFS).

The Faculty of Forestry, Kasetsart University in Thailand was assigned as the Regional Project Manager. In addition, nine consultants were recruited to assist the participating countries to implement the planned activities and arrange training courses during 3 years period starting January 2019. However, as a result of COVID-19 pandemic that started early 2020, all participating countries imposed strong measures to cope with the global pandemic such as travel restriction, social distancing and work from home. A lot of planned activities were cancelled or rescheduled. Therefore, the project duration was extended for 6 months until September 2022without additional cost.

The Teak project in Mekong conforms with ITTO's objectives and Strategic Action Plan (SAP 2022-2026) towards promotions of the expansion and diversification of international trade in tropical timber from sustainably managed and legally harvested forests. The project contributes to the achievement of SDGs, especially SDG 1 (No Poverty), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on land), and the Global Forest Goals of the United Nations Strategic Plan for Forests 2030 (UNSPF). The project also supports the participating countries' policies and strategies on sustainable forest management and sustainable wood supply from legal sources in line with their Nationally Determined Contributions (NDCs). For example, Thai's National Forest Policy adopted by the cabinet in 2019 aims to maintain 40% forest cover of which 25% conservation forests and the remaining 15% production forests.

In order to achieve these strategic goals of production forests and wood industries, Thai government promotes afforestation in private and public land; promotes and assists value chain process in wood industries and biodiversity-based economy development; licensing and national and international certification of timber, including small- and medium-sized enterprises. Most importantly, Article 7 of the Forest Act 2019 (amended from 1941) stated that the previously restricted tree species, in particular teak either planted in the public land or private own land are no longer defined as restricted species. Similar policies and approaches are also practiced in the participating countries.

Photo 1-1 Launching and 1st PSC meeting, Bangkok on 24 April 2019 (left) and 2nd PSC meeting in Vientiane, Lao PDR on 20 February 2020 (right)

This publication presents a collective work and achievements made by the five participating countries to strengthen on-going strategic objectives and policies on the sustainable development of teak forest resources, in particular livelihood improvement and ecological significance in all countries of the GMS. In addition, the three outputs expected from the project were: output 1-conservation of teak genetic resources, sustainable management and use of natural teak forests and market accesses of teak from legal sources have been improved; output 2-community-based and smallholders teak forest management and agroforestry systems have been strengthened with improved legal and sustainable supply chains; and output 3-regional and international collaboration, information sharing and knowledge management, networking, policy development and outreach on the sustainable management of teak forests, including sustainable use of teak genetic resources have been strengthened.

Conservation of Teak Genetic Resources

Natural teak distribution

Natural teak forests occur within a latitudinal range of 10° to 25°N (Gyi & Tint, 1995) in South and Southeast Asia, especially India, Myanmar, Thailand and Lao PDR. Kollert & Cherubini (2012) reported that natural teak forests cover approximately 29 million hectares of which Myanmar alone occupies almost 50 percent area of natural teak forests. Natural distribution of teak occurs in the semi-evergreen forests, mixed deciduous forests and deciduous dipterocarp forests. Mixed deciduous forest produces teak with clear and straight boles compared to other forest types (Kermode, 1957). Thailand has the second largest area of natural teak forests (after Myanmar) at an estimated 8.7 million ha mainly distributed in northern Thailand. In the 1970s Lao PDR had about 70,000 ha natural teak forests, and in 2010, only about 1,500 ha are left. They are mainly located in north-western Lao PDR adjoining Thailand border. Currently, only fragments of the original teak forests in Thailand and Lao PDR remain mainly in a few protected areas. Vietnam and Cambodia do not have natural teak forests, but in Vietnam planted forests has been introduced by the French in 1952 and Lao PDR in 1985.

The remaining suitable range of teak forests in 2019 covers 18.90 million ha, which was substantially different with the estimation by Kollert & Cherubini (2012) due to unsustainable logging and encroachment for agriculture and future climate change (Chapter 8). About 43% of the remaining total teak occurrence (8.1 million ha) was predicted in Myanmar, whereas 41% (7.7 million ha) and 16% (3 million ha) are located in Thailand and Lao PDR, respectively. Substantial loss has been detected in Myanmar due to unsustainable logging (Forest Department, 2000; FAO, 2020). Comparatively less reduction is predicted in future as a result of the logging ban in India, Lao PDR, Thailand and Myanmar, and the governments allowed only a limited sustainable harvest from natural forests (Roshetko et al.,2013).

However, actual extent of natural teak forests at present (Chapter 7) is significantly less than the suitable area derived from the species distribution model.

Teak has been widely established in plantations throughout the seasonally dry tropics as a high value tropical hardwood. Planted teak forests according to various estimates has reached approximately 6.89 million ha of which 80% are grown in Asia followed by 10% in Africa and 6% in the Latin America.

Teak genetics

Though teak has been widely planted across the world, reliable information on genetic variation within and among populations, and among regions is important to ensure the long-term survival of a species and establish conservation stand and commercial plantations effectively in a changing environment. Teak occurs naturally in a wide range of climatic conditions. However, the optimal temperature ranges from 25°C to 35°C with the optimum annual precipitation between 1,250 – 2,500 mm associated with a dry period of 3-5 months are most suitable for the production of good quality timber (Kaosa-ard, 1981).

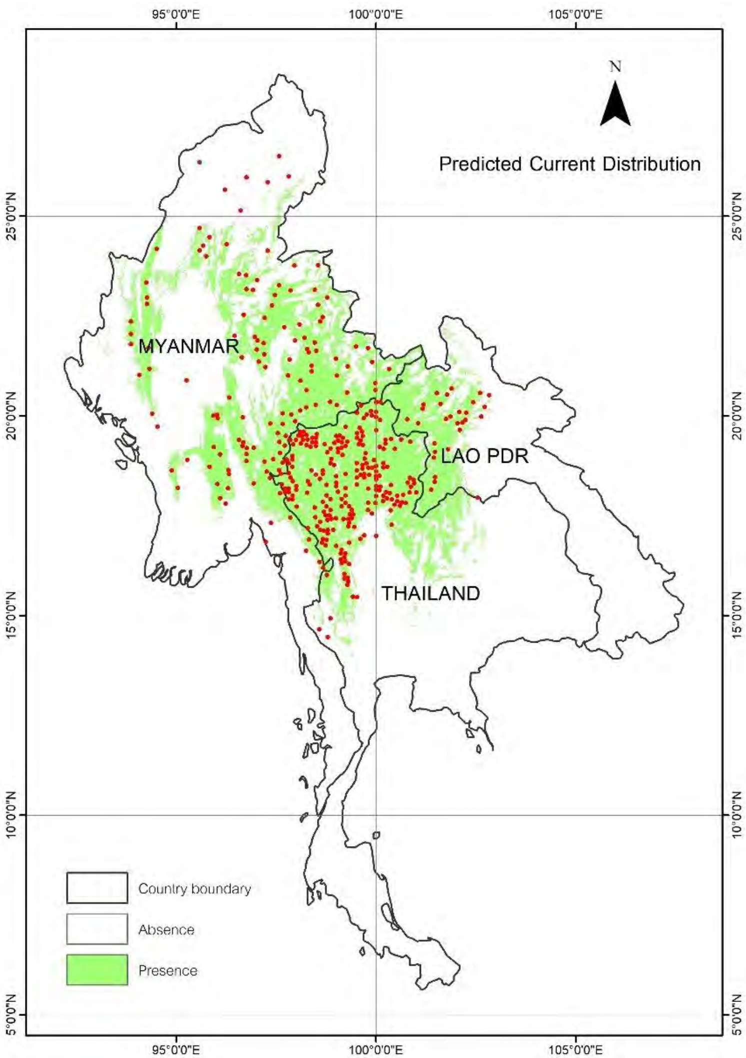


Figure 1-1 Potential suitable habitats at baseline

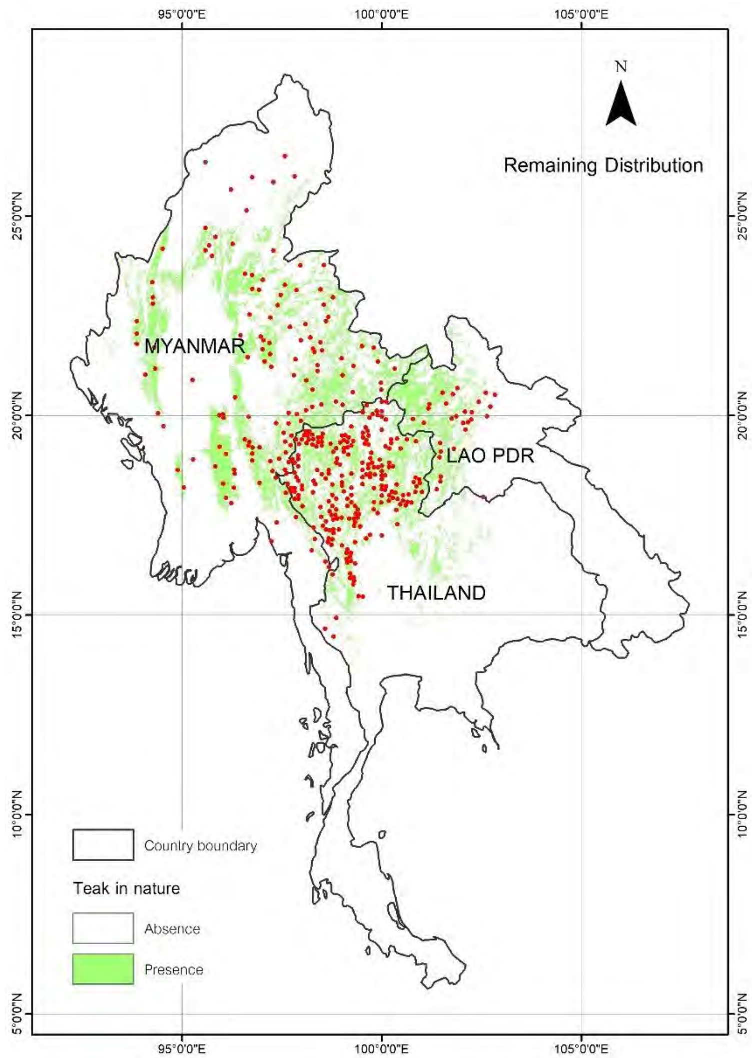


Figure 1-2 Remaining suitable habitats at baseline (masked by land use map)

Seth & Khan (1958) and Champion & Seth (1968) classified the teak forests in India into 5 ecological zonation by correlating the amount of annual rainfall, stand composition and the qualities of teak into five types. Ranging from very moist teak forest (annual rainfall > 2,500 mm) to very dry teak forest (annual rainfall <900 mm). Using the similar approach, Kaosa-ard (1979) classified natural teak forests in Thailand into 4 zones using P:T ratio moisture index method, where P is annual rainfall in mm, and T is annual mean temperature as follows: Zone 1: dry-humid zone with the P/T ratio smaller than 40; Zone 2: medium-humid zone with P/T ratio of 40-50; Zone 3: moist-humid zone with P/T ratio of 50-60; and Zone 4: wet zone with P/T ratio of greater than 60.

Teak Genetic and Tree Improvement

Based on teak genetic Consultant's comprehensive literature review, the present status of teak genetic and tree improvement in the five participating countries are elaborated below.

Myanmar

Geographic variation of teak in Myanmar was observed in both provenance trails and molecular genetic studies. The results of investigations indicated that Myanmar teak has at least four groups of genetic components which corresponds to four genetic clusters spread over in the geographic regions of lower, central, upper, and southern regions, respectively. Almost all genetic studies of native teak congruently suggested that Myanmar teak has higher genetic diversity than Thailand and Lao teak, similar to central Indian teak. Among the four clusters, teak populations from lower region (around Bago Yoma) showed slightly higher genetic diversity than upper and central teak populations, while southern populations exhibited the lowest genetic diversity (Win, 2022). Nevertheless, Myanmar teak populations possess high level of genetic diversity. The genetic diversity does not show significant difference between selective logging and unlogged teak forests in Myanmar.

Teak tree improvement program was started in Myanmar since 1981 through the establishment of clonal seed orchards in Letpankon, Oaktwin consisting of 33 clones. A total of 1,011 plus trees of teak were selected throughout Myanmar representing almost all teak growing regions, of which 856 trees were selected during the Myanmar Reforestation and Rehabilitation Programme (MRRP) project phase. These plus trees are important for evolutionary conservation of Myanmar teak. Clones from some plus trees were planted in six clonal seed orchards in 6.3 ha area and seven hedge gardens in 7.6 ha area, serving as gene pool for *ex situ* conservation. For propagation, shoots from these clones are used for producing clonal materials. Currently 207 teak seed production areas in fourteen out of fifteen regions having an area of 2,815 ha were transformed into seed production areas (SPAs).

No progeny test for selected clones nor genetic studies of teak clonal seed orchard (CSO) or plus trees had been conducted before 2019. The ITTO Teak Project provided funding support for a progeny trial to test genetic characteristics of candidate plus trees using clones in gene bank plantation. Seeds obtained from selected clone was used to raise seedlings for the progeny test. It is expected to collect data for progeny test after 3 years. The results of progeny will be used to determine plus trees for future tree improvement program of teak.

In addition, a new teak CSO was established as a demonstration plot at Moe Sew Research Station, Myanmar in June 2020. The teak CSO, 0.8 ha area is composed of 260 meters representing 20 clones collected from different teak sources across Myanmar. The teak CSO has been maintained by the project. Survival counting was conducted in December 2020, weeding, fencing and periodical measurements were accomplished during the reporting period of Jan-June 2021. Apart from being a demonstration plot, the teak CSO also serve as a research centre of the Forest Department, and support of ITTO Mekong-Teak project is crucial for future teak improvement program.

Tissue culture technique and cutting methods can be successfully practiced in Myanmar for clonal materials. However, no large-scale production of planting materials from plus trees produced via tissue culture laboratories existed for commercial plantations. During this project phase, gene bank of Myanmar teak and a new hedge garden was established in Forest Research Institute using the clones. Subsequently, the planting materials produced from these labs will be planted in clone bank used for mass propagation and establishment of teak clonal plantations.

Thailand

Teak genetic improvement in Thailand began in 1965 under a bilateral agreement between Thailand and Danish governments. A total of 636 plus trees were selected across the natural teak forests in Thailand according to growth performance, stem form, wood quality, and the health of the tree criteria. Of these 509 plus trees were planted in 5 clone banks across the country. Three sets of clonal test were conducted, the first one using budding techniques for propagation for 100 clones and tested at one site. Second set of clonal test was conducted using rooted cuttings for vegetative propagation for 400 clones at 4 sites. The last set of 100 clones has recently been established at Maegar Silvicultural Research Station in Payao Province as part of the ITTO-Mekong Teak project in 2021. The objective of this clonal test was to evaluate genotypic value of the remaining plus trees located in different environment.

The seedlings derived from the clonal test were planted at 3 experiment sites: 1) Dong Lan SRS, Khon Kaen Province, 2) Krueng Krawia Forest Plantation in Kanchanaburi Province, and 3) Thung Kwien Forest Plantation in Lampang Province. The first site is under the RFD, while the remaining two sites are under the Forest Industrial Organization (FIO). The duration of the project is 5 years under cooperation between the RFD and Kasetsart University with the financial support from the ITTO Teak Project in Mekong. Progeny tests using full-sib progeny and half-sib progeny were employed to identify trees of better genetic quality. These high-quality teak seedlings produced from tissue culture or shoot cutting of good material are now available for use by farmers for producing high quality teak timber. See details in Chapter 21.

Thai natural teak forests display a high genetic diversity and form, the Thai teak germplasm (seedlings and clones) has been globally used in many tropical countries for plantation establishment often without knowing its provenance or origin. Natural distribution of teak forests are confined to northern and western Thailand between latitudes 16-21°. They are separated into seven gene-ecological zones based on the results of provenance trials, climate, topography and soil factors (See details in Chapter 2). For over 50 years, the results showed that genetic improvement resulted in improved teak varieties, which grow faster, produce good quality wood and resist pests and diseases. Teak improvement program such as development of cutting techniques, pollination technique, use of molecular technology and use of Index selection coupled with Forward selection in offspring test for establishment of the seed production areas has lead to modern breeding strategy with high accuracy and efficacy.

Photo 1-2 Teak clonal seed orchard (CSO) in Myanmar (upper right), clonal test in Thailand (upper left), seed orchard (lower left) and tissue culture lab in Thailand (lower right), being maintained under the ITTO Mekong (Teak) Project

Lao PDR

As previously mentioned, teak is a priority native species in Lao PDR. Natural teak forests are found in north-western provinces of Lao PDR. Laos teak has the lowest genetic diversity compared to other countries like Indian teak (Win, 2022). It has remarkable genetic difference with Indian and Myanmar teak, but southern Lao population was similar to Thailand teak (Win, 2022). No significant difference was observed in genetic variation of Lao intra-populations.

In Laos, teak genetic improvement efforts dates back to the 1990s as part of the Laos Tree Seed Project. This project took an important role in both the *in situ* and *ex situ* conservation of important tree species in Laos and the establishment of seed production areas. Of the total 102 seed sources, nine are for the teak seed sources established in it natural habitats. However, most of these seed production areas have either been harvested or transferred to private owners. The ITTO Teak project in Mekong supports NAFRI to establish 2 demonstration plots for teak seed production. A total of 100 mother trees at Thong Khang and 178 mother trees at Huay Khodin Xayabuly Province were selected for teak seed source production situated at Na Sak, Kengsao and Sisa-ard village for smallholder plantations. In addition, teak seed source from 170 mother trees in Luang Prabang province were chosen for establishment of Nam Suag Forest Research Center (Table 1-1).

Clones of those selected trees were maintained at three clonal banks. Improved seedlings derived from the selected trees, clone bank and clonal seed orchards have been distributed to farmers for developing their plantations.

Cambodia

Natural teak forests do not occur in Cambodia, but it is included in the list of species used for reforestation program along with *Hopea odorata*, *Dipterocarpus* spp., *Pinus merkusii* and fast-growing fuelwood species. Teak plantation in Cambodia was commenced in 1936 in the first reforestation attempt by intercropping teak with cotton and maize in Han Chey commune, Kampong Cham province as an agroforestry system supervised by French (Pierre, 1947).

A number of teak plantations were established in the late 1970s in Kampong Cham, Pursat and Rattanak Kiri provinces. Since 1990s, afforestation in Cambodia was resumed and vast majority of tree plantations were promoted, not only by state in open forest areas, degraded mountainous areas and watersheds, but also private sectors. The MAFF promulgates the Declaration on the Establishment of Private Forests to promote and incentivize individuals or legal entities to plant trees on their own legally acquired land as a means of increasing timber production and fuelwood supplies for domestic consumption and export.

There is no seed source of teak in Cambodia. Seeds are imported from Thailand by some private companies in the early 2000s. With the support of ITTO Teak project in Mekong, Cambodia, has established 2 seed sources at Han Chey Mountain in Kampong Cham Province and Teak silvicultural practice in Kampong Spue Province for production of high-quality seedlings. Teak plantations currently exist between 6,200 and 7,000 ha. The number of major teak plantations reported is 6,100 ha in 6 provinces including Tbong Khmum, Kampong Cham, Kratie, Ratanakiri, Kampong Speu, and Kampot.

Vietnam

Similar to Cambodia, teak is not a native species in Vietnam. Teak was first introduced in Vietnam by the French in 1889 in the north and south regions, largely in parks and along road sides. The five major species of plantations are Acacia, Rubber, Pinus, Eucalyptus, and Bamboos for production purpose. Most plantations have been established in the Taungya System as a mixture with food crops (rice, maize, green bean, soya), for which a silvicultural management system has been developed that allows for the production of high-value timber.

During the period 1993 to 2010, teak was in the list of the major tree species for planting in the two national large-scale afforestation programs. Data from national forest inventory 2016 compiled in FORMIS II Project (2017) showed that teak plantations cover about 6,600 ha, about 0.15% of the country's plantations. Major teak plantations were observed in the Son La province of northwest, in Dak Lak province, central highland, and in Dong Nai province, southeast. The ITTO Teak project in Mekong supports the establishment and maintenance of 3 teak seed source production centres, namely Dong Nai Teak Plantation, Son La Teak Plantation and Thanh Hoa Station. Good quality teak seedlings have been prepared at demonstration plots. More than 6,000 high quality seedlings were distributed to smallholders. The target number is 15,000 seedlings. Myanmar and Vietnam components have produced over 15,000 seedlings for each country under this project.

Cambodia, Lao PDR (2 seed sources) and Vietnam components also established demonstration plots. The main objectives are for teak seed production and silvicultural practices rather than for clonal tests.

Photo 1-3 Teak nursery at Kampong Speu demonstration plot, Cambodia (left) and The ITTO Mekong (Teak) Project provides genetically sound teak seedlings to the community (right)

Community-based and smallholders teak forest management and agroforestry systems have been strengthened with improved legal and sustainable supply chains.

ITTO Teak Project in Mekong is aimed at assisting governments, local communities and smallholders to enhance natural teak forest management, production and marketing to facilitate the establishment of legal and sustainable wood supply chains. The RFD of Thailand and Forest Administration of Cambodia developed criteria and indicators for the selection of demonstration plots establishment and appointed Demonstration Selection Committees to advise the project to choose the demonstration plots. In the last 3 years, 14 demonstration plots (Table 1-1) have been established for production of good quality seedlings that was freely distributed to interested local communities and smallholders. In addition, learning centers for good practices in agro-forestry and silvicultural practices has been included for small-scale plantation.

Table 1-1 Demonstration plots established by the ITTO Teak Project in Mekong

No	Name	Location	Role in supply chains
Cambodia			
1	Han Chey Mountain (10 plots, 625 m2 each)	Kampong Seam District, Kampong Cham Province	10 small plots for silvicultural practice
2	Teak silvicultural practice (12 plots; 625 m2 each)	Kampong Spue Province	12 small plots for silvicultural practice
Lao PDR			
1	Nam Suag Forest Research Center, Ban HoayKhod, Number 3 and Nakha village	XiengNgeing District, Luang Prabang Province	Teak seed source from plantation (170 mother trees)
2	Na Sak, Kengsao and Sisa-ard village	Pakllai District, Xayabuly Province	Natural teak seed source (100 mother trees at Thong Khang and 178 mother trees at HuayKhod)

No	Name	Location	Role in supply chains
Myanmar			
1	Moe Swe Research Station No.5, Oattarathiri Township, Nay Pyi Taw	Oattarathiri Township, Nay Pyi Taw	Silvicultural practice, supply of quality seed and genetic resource
2	Letpankhon Forest Resarch Station No. 7, Oaktwin Township, Bago Region	Oaktwin Township, Bago Region	Agro-forestry practice, supply of quality seed
Thailand			
1	Mae Ka Silvicultural Research Station	Mae Ka district, Phayao Province	Teak seed orchard, preparation of good material
2	Ngao Silvicultural Research Station	Ngao district, Lampang Province	Teak seedling production and smallholder networking
3	Smallholder Teak Plantation (Mr. Suchat Poolkerd)	Hang Chat district, Lampang Province	Demonstration for thinning, pruning and growth estimation
4	Khunmae Kummae Teak Plantation	Rongkwang District, Phrae Province	harvesting demonstration
5	Community-based teak plantation (enterprise)	Nan province	Community-based wood harvesting and processing through C&I and CoC
Vietnam			
1	Dong Nai Teak Plantation	Teak Plantation	Teak seed source
2	Son La Teak Plantation	Son La Province	Teak seed source
3	Thanh Hoa	Thanh Hoa	Seed production


Photo 1-4 ITTO Project team visited smallholder teak plantations in Son La Province, Viet Nam (left) and Teak smallholders' networking workshop at Ngao Silvicultural Station,Thailand (right)

The project team with the technical support of consultants conducted training workshops to increase capacity of government staff in central and field offices, teak farmers and interested individuals on the following themes: (1) seed production/nursery techniques, (2) silvicultural practices and improved stand management, and (3) minimizing harvesting loss, efficient transport and processing of teak round wood, and (4) supply chains control and marketing. The first training workshop on Seed Production and Silvicultural Practices was conducted in Lampang province, Thailand on 5-9 August 2019. After get trained, the participants from Vietnam, Lao PDR, and Cambodia became the instructors to train interested staff and local people in their own countries.

As of March 2022, there were 21 training courses conducted with more than 750 participants. Thailand Component organized 5 training courses for 177 participants affiliated with the RFD and FIO, teak smallholders, interested individuals across the country. In Lao PDR, about 250 local people from 6 villages situated in 3 pilot provinces namely Luang Prabang and Paklai, Xayabuly province were trained on Sivilcultural Techniques on teak plantation and tree seed management and network establishment. Cambodia component conducted 2 training sessions on silviculural practices and seed production with 46 participants. Myanmar conducted 6 training courses covering various aspects of silvicultural practices such as teak grafting, teak hedge garden establishment and Plus tree selection, teak improvement, and teak based agro-forestry systems. The number of participants for each training varied between 20 and 30 persons from communities and field office of Forest Research Institute. Vietnam also conducted 4 training workshops on seedling production and planting techniques (a series training course) in 2 pilot provinces (Thanh Hoa and Son La). The number of participants was 20 persons for each session. As a result of COVID-19 outbreak, Vietnam component arranged a series of online Teak Value Chains Analysis (VCA) for participants from 5 countries. Similar to Myanmar component, 2 online trainings on tree improvement were conducted in July 2021.

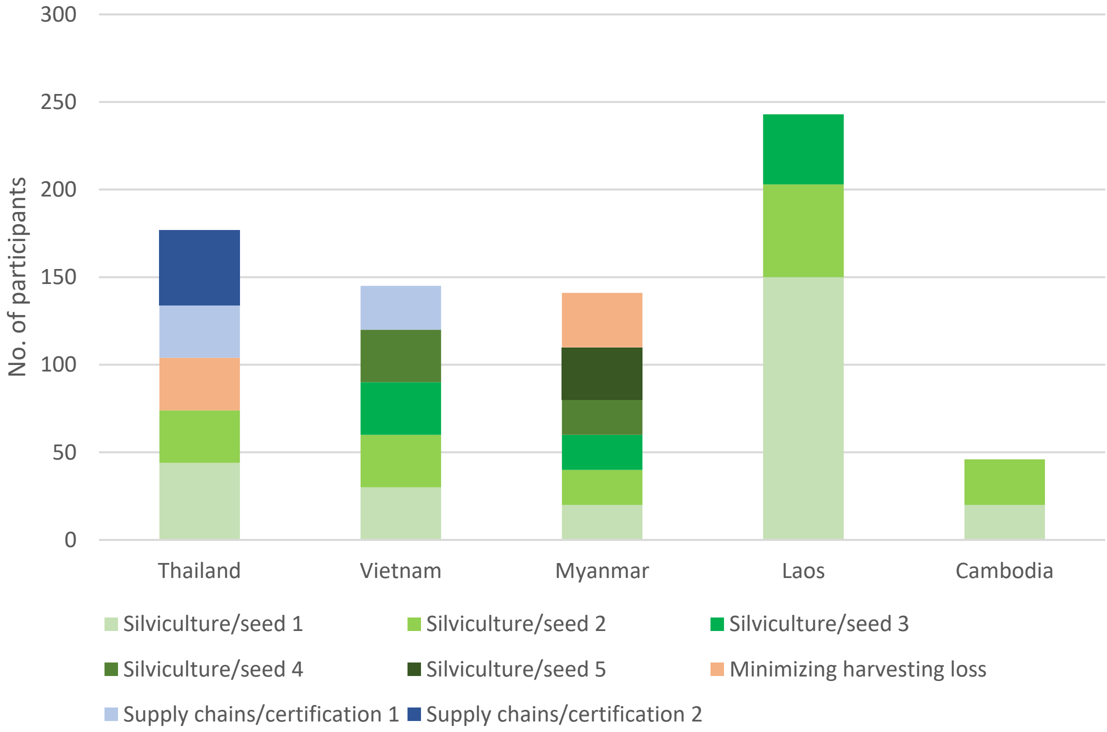


Figure 1-3 Training sessions and number of participants

Photo 1-5 Myanmar National Coordinator visited teak planting stock (upper left), Training workshop in Thanh Hoa (upper right), Training on Silviculture techniques (lower left) and Teak improvement technique training, 10-13 July, 14-17 July 2021 at FRI Office and online training to District staff and smallholders, October 2019, Laos (lower right)

The VCA of smallholders aims to increase their access to markets by improved primary processing as well as capital and market information. Prof. Dr. Tek Maraseni, an international VCA expert from University of Southern Queensland provided the training and support to write report on teak VCA.

Photo 1-6 Interview of teak wood trader in Son La Province, Vietnam

Teak-Based Forest User Groups

Experts from timber production and consumer countries discussed and agreed during the ITTC-57 that the COVID-19 will remain a significant problem on the tropical timber trade market, international prices and demand are expected to decline. In addition, the political and structural limitations that affect the region will persist, and logistics will continue to be a major problem. There have been disruptions in supply chains, leading to limited sales of tropical timber in global market. In contrast, the RFD, Thailand reported that the domestic wood production is predicted a steady increase due to substantial decrease of imported wood products and residential property development in big cities and the government's property stimulus package for buying new homes. The Forestry Development Strategy (2017 – 2036) predicts an annual wood demand of 47 million tons. This huge demand can be met by either the additional forest plantations of 1.4 million ha by 2036.

In addition, the Governments of all participating countries promulgated the ban on logging of natural forest and accelerated plantation forestry, provide income for farmers, improve environment and secure raw material for wood industries. Although, the project document aimed to promote the establishment of teak-based forest user group only in Myanmar, the remaining four participating countries also identified teak-based forest groups. In Myanmar, teak-based agroforestry in Moe Swe area, Ottara

Thiri Township, Nay Pyi Taw was established. Individual meeting, discussion with potential user group members and visit to the community were arranged. Genetically sound and vigorous teak seedlings, intercrop plants and other necessary techniques were provided by the project, while every user group member on the other hand, is given preference in choosing planting design, spacing, quantity and type of planting species particularly for intercrop plant species.

Meanwhile, Thailand component organized two workshops on teak smallholders' networking in northeast and north Thailand. More than 65 farmers and field staff of relevant agencies participated. Participants had opportunities to visit small-scale teak plantation and agro-forestry practice (Mr. Suchat Poolkerd's plot) and explores direct experience from Mr. Suchat Poolkerd in Lampang Province. In addition, two communication line groups were created to share experience and knowledge. Furthermore, Maegae Silvicultural Research Station provided teak seedlings, technical support, and limited budget to improve water resources at the agro-forestry plot.

Photo 1-7 Project provides genetically sound teak seedlings (Myanmar-left) and small fund to community (Thailand-right)

Government Policies and Governance

The smallholder teak growers across the Mekong region face a host of problems in accessing the best quality planting stock, in managing the crop to maturity, in growing interim crops for regular incomes, in harvesting and transporting timber, in obtaining certification, and in fetching the best prices for their produce. The changing climate is also leading to increasing incidences of fires, insect attacks and diseases which often originate in adjacent large natural forest areas. Besides, there are also new opportunities like the market and non-market approaches of the Paris Climate Agreement which have the potential of making the teak grower more competitive in the market place.

Site quality has a dominant role in determining the productivity, and profitability, of teak plantations and, therefore, it is important that the smallholders should be guided and encouraged to opt for the best available sites. Criteria for site selection for teak plantations should be refined, harmonized and widely disseminated. Site management to sustain and enhance productivity may involve changes in silvicultural prescriptions, soil conservation measures and fertilizer application. New protocols, specifically for smallholders, need to be developed for this purpose.

Assured supply of high-quality planting stock delivered at reasonable prices at locations that are manageable for smallholders is one of the most important demand of the small growers. The forestry departments of the region may produce certified high-quality teak planting stock offering a good range of choices that are well advertised, and make it available through a chain of outlets.

The fear of losing control over land if planted with teak trees is deep among the landholders in the Mekong sub-region. The reason a smallholder plants teak on his land is maximization of his earnings and not for inviting restrictions on his enjoyment of his land assets. If any other ecological or social objectives are to be added to his personal goals in planting teak for public good then, as a matter of principle, the government must be willing to compensate the smallholder for the consequential losses incurred by him. In the interest of promoting teak planting by smallholders every country in the region should incorporate this principle in their policies.

Policies and legislation in some countries of the region, introduced during colonial times to protect government owned natural forests from illegal felling, placing restrictions on the transport of teak harvested from private lands act as severe disincentive for smallholders who find it difficult to obtain the required permissions to transport their timber to the sawmills and market and often become victim of corrupt practices. The task of protection of teak in natural forests is a duty of the State the cost of which should be borne by the State and not by individual smallholders who take to teak growing as a normal economic activity. It is strongly recommended that the governments of the countries in the Mekong region may consider removing the restrictions on transport of teak from plantations altogether and instead rely on in-situ protection of their natural teak resources using appropriate technologies.

The outcome of total ban on teak felling in natural forests enforced in Thailand and Lao PDR is not without significant risks in having precious natural forests with large number of old, diseased and decaying trees that could become host to huge infestations of insects and pests and greatly increase the risk of wildfires. In National Parks with too high a density of teak trees discourages grass growth on the forest floor reducing the carrying capacity for wild ungulates which in turn affects the populations of predators. So a regular, but light, selection felling of old, dead and dying teak trees might be advisable in these forests.

Higher prices in niche markets where consumers are prepared to pay a premium price for teak obtained from sustainably managed areas are an incentive to produce certified timber. But the costs of certification process are quite high and usually prohibitive for smallholders. And also the niche markets willing to pay higher prices for certified timber may not be accessible to all small growers. The governments in the region may help set up autonomous independent certification bodies that offer low cost certification services to small growers.

Plantations located adjacent to the government forests are often exposed to fires that originate within forests and cannot be controlled by outside efforts. Less often they face similar problems with tree diseases and insect attacks too, that originate within adjacent large sized government forests. A clear expectation of the smallholders is that reducing these losses, and compensating them, if necessary, is the responsibility of the State.

Teak prices are very closely related to wood quality which is determined by dimension, bole shape in terms of roundness and straightness, heartwood-sapwood ratio, regularity of annual rings, number of knots, colour, texture and the soundness of the butt log. But since no common international log grading rules exist it is very difficult for producers of higher-grade timber to access consumers of those grades in distant markets. The ITTO is best placed to facilitate the introduction of common timber grading rules across the international markets.

There are unsubstantiated claims of teak plantations having a deleterious effect on the productivity of agricultural lands downstream and even on the site quality of forests below. This needs deeper investigations by forestry universities and research institutions in collaboration with agricultural universities and quick dissemination of the outcomes as they emerge. Another potential area for management research in teak is the impact of long, medium and short rotations in teak natural forests and plantations on soil, ground vegetation, water regime, and on teak production which have not yet been systematically assessed and are subject to much speculation. This research task is also best undertaken by forestry universities and research institutions in the region and ITTO is well placed to facilitate this process.

Regional and International Collaboration, Information Sharing

Recognizing the importance of teak and the lack of a common platform to share the multifaceted problems faced by planters and investors dealing with teak cultivation and management of natural and planted teak forests, the International Teak Information Network (TEAKNET) established by FAO of the United Nations currently functioning from the Kerala Forest Research Institute is supporting the global teak community by way of producing and disseminating outreach and training materials, trade and marketing information of teak exported to different destinations etc through the web portal www.teaknet.org. TEAKNET was a project partner in the 2017 IUFRO publication No. 36 (Global Teak Study Report).

In the on-going ITTO Teak Mekong project, TEAKNET is involved with the specific objective of supporting and facilitating teak networking in the Mekong Sub-region through ITTO's member countries and partners such as collaborating with other regional cooperation frameworks to promote the conservation and sustainable management of teak forest resources, including legal and sustainable supply chains to facilitate transformational change through integration into national development programs for development of sustainable teak-based forest sector. As part of it, since 2019, a bimonthly online *Teak Mekong Newsletter* was released through the TEAKNET webpage www.teaknet.org and co-hosted by Kasetsart University, Thailand and widely circulated to the global teak community including the social media platforms of Youtube and Facebook page. The newsletter carries success stories and support sharing lessons of the project results through short news release, occasional papers, project related teak-based research and development information. So far 18 issues of newsletter was released online.

TEAKNET in collaboration with FAO, IUFRO and ITTO co-organized three World Teak Conferences in Costa Rica (2011), Thailand (2013) and Ecuador (2015) that were attended by over 1,000 representatives of the major teak growing countries in Asia/Oceania, Africa and Latin America. Besides sharing the information through the website and newsletters, the project findings also will be disseminated by co-organizing the 4th World Teak Conference 2022 during 5-8 September, Accra, Ghana in which ITTO project partners will assemble for a special ITTO side event planned. Thus, at the end of the project, it is anticipated to accomplish regional and international collaboration, information sharing and knowledge management, networking have been strengthened far beyond GMS region and capable to extend its collaborative activities to other parts of teak growing countries in Latin America and Africa.

Overview of This Book

This edited book entitled "**Sustainable Management of Teak (*Tectona grandis* L.f.) in the Mekong Region**" aims to demonstrate a comprehensive assessment of various aspects and activities of the teak project that has been undertaken to contribute to (1) the conservation of teak genetic resources, sustainable management and use of natural teak forests and market accesses of teak from legal sources have been improved, and (2) to strengthen capacity of communities, smallholders of teak plantations and responsible government institutions on legal and sustainable supply chains, as well as teak-wood certification. In addition, (3) lesson-learned and experiences on the sustainable management of teak forests, including sustainable use of teak genetic resources are shared among multi-stakeholders in the region.

This book contains 27 chapters in six sections. ***Section One: Introduction*** (this chapter) summarize key finds and achievements of the project. ***Section Two: Teak distribution across the Greater Mekong Sub-region*** (7 chapters) presents natural teak forests distribution, teak plantations and management in the five participating countries. ***Section Three: Silvicultural practices and teak improvement*** (7 chapters) presents various teak improvement techniques, silvicultural practices and Insect Pests and their Management in teak plantation not only in the GMS but also in Malaysia, Indonesia and Brazil. ***Section Four: Sustainable teak forest management and certification*** (4 chapters) presents the share practices on sustainable teak forest management, certification, wood consumption and international trade, and its contribution to environment such as carbon storage from several countries. ***Section Five: Research in teak genetics*** (3 chapters) presents on-going both in theory and in practices of genetic conservation and improvement, clonal test and good quality seedling production in the Mekong region but not limited to the five participating countries. ***Section Six: Policy and regional/ international collaboration*** (5 chapters) reviews relevant laws and regulations on sustainable production and trade of teak, and discusses governance concerns and makes recommendation for sustainable teak forest management in particular for smallholders in GMS, as well as explore knowledge management and teak information networking. In addition, Chapter 27 *The Way Forward - Teak in Mekong for a Sustainable Future* provides some recommendations for future work related to management of natural teak forests and plantations, conservation of teak genetic resources and Considerations for Tree Improvement, ccommunity-based smallholders manage-ment, certification and legality, and regional network and international collaboration.

References

Champion, H. G. & Seth, S. K. (1968). *A Revised survey of the forest types of India:*113-117, 181- 184. Manager of Publications, Delhi, India.

FAO. (Food and Agriculture Organization of the United Nations) (2020). *The Global Forest Resources Assessment 2020*. Summary Report. Committee on Forestry., Rome, Italy.

Forest Department. (2000). *Historical review of teak forestry in Myanmar- A paper presented at the Third Regional Seminar on Teak held from 31 July- 5 August 2000*, Yogyakarta, Indonesia. 13 p.

Gyi, K. K. & Tint, K. (1995). *Management Status of Natural Teak Forests, Asia-Pacific Network on teak research and development*. First Regional Seminar on Teak Forest Department, Myanmar.

Kaosa-ard, A. (1979). *Teak Seed Centre. Annual Report No.1.* Teak Seed Centre, Ngao, Lampang, Thailand, 35 p.

Kaosa-ard, A. (1981). (Teak *Tectona grandis* Linn.f.) its natural distribution and related factors. *Natural History Bulletin of the Siam Society, 29*, 55-74.

Kermode, C. W. D. (1957). Teak. In: *Tropical Silviculture vol. 2*, pp. 168-178. FAO, Rome, Italy.

Kollert, W. & Cherubini, L. (2012). *Teak resources and market assessment*. Planted Forests and Trees Working Paper FP/47/E. Edited by Food and Agriculture Organization of the United Nations. Rome. http://www.fao.org/3/an537e/an537e00.pdf (accessed 5 March 2021).

Pierre, A. (1947). Enlargement of Reforestation Modes by Intercalary Agricultural Crops. Birth of Agroforestry in Indochina.

Roshetko, J. M., Rohadi, D., Perdana, A., Sabastian, G., Nuryartono, N., Pramono, A. A., & Kusumowardhani, N. (2013). Teak agroforestry systems for livelihood enhancement, industrial timber production, and environmental rehabilitation. *Forests, Trees and Livelihoods*, 22(4), 241-256.

Seth. S. K. & Khan, M. A. W. (1958). Regeneration of teak forests. In: *All India Teak Study Tour 1957-1958*, pp. 107-120. F.R.I., Dehra Dun.

Win, T. T. (2022). *Overview of Genetic Resources and genetic Conservation of Teak in Mekong Sub-region*. Final Technical Report submitted to Forest Department, Naypyidaw, Myanmar.

SECTION II

TEAK DISTRIBUTION ACROSS THE GREATER MEKONG SUB-REGION

Chapter 2: Teak Management in Thailand

Sapol Boonsermsuk

Abstract

Teak (*Tectona grandis* L.f.) is high value timber species native to Thailand. Illegal logging and forest encroachment over the past few decades, and regulatory restrictions are key concerns of the teak wood industry in Thailand. Thailand's 20-year National Strategy (2018-2037) targetted at increasing the forest cover up to 40 percent of the land area, followed by very significant amendments to forest laws and regulations enacted in 2019, is aimed at motivating people to plant more trees for economic benefits and enrich the timber trade. Teak is promoted as one of the top priority species for planting in Thailand and exempted from the list of restricted species. Genetically improved planting materials are required to obtain good timber characteristics and enhance productivity of teak from plantations for long-term investment. This article highlights the industry, trade and marketing information related to teak Thailand that may be of use in promoting investment in the teak plantation business.

Introduction

Teak (*Tectona grandis* L f.), family Lamiaceae, grows in tropical deciduous forests and its natural habitat is limited to Southeast Asian countries of India, Myanmar, Thailand, and Laos (Kollert & Cherubini, 2012).

Teak is a gregarious species found in mixed deciduous forests of northern Thailand provinces of Mae Hong Son, Chiang Rai, Chiang Mai, Payao, Lamphun, Lampang, Phrae, Nan, Sukhothai, Uttaradit, Phitsanulok, Phichit, Phetchabun, Tak, Kamphaeng Phet, Nakhon Sawan and Uthai Thani. The southern boundary limit of teak in Thailand is 16°30' latitude and its altitudinal range is mostly between 100-900 meters above mean sea level (msl.) (Mahaphol, 1954; Pandey & Brown, 2000) though it is also found in patches in higher altitudes of up to 1,300 msl as in "Nawamintara Rachinee teak forest" located in the Pai River Wildlife Sanctuary, Mae Hong Son Province (Photo 2-1) (RFD, 2013).

Teak is a valuable tree because of the desirable properties of its timber, such as strength, durability, stability and non-corroding properties. The quality of teak in Thailand is as same as teak in Myanmar, which is considered the best Teak in the world and is in high demand in the world market. According to historical evidence from the survey of archaeological sites, Thailand has been using teak from natural forests for more than two thousand years (Pumijumnong, 1995).

Photo 2-1 Nawamintara Rachinee teak forest, Mae Hong Son Province

Teak forests generated a lot of income from exports for Thailand in the past. Small-scale teak logging concession was granted to Chinese and Burmese traders in 1829, and large-scale trade rights were granted to British Borneo Company Ltd in 1864 (RFD, 2013). Thai teak forests are under pressure, which have already suffered severe over-exploitation, shifting cultivation and more intensive modern agriculture (Gajaseni & Jordan, 1990). Kollert & Cherubini (2012) reported that natural teak forests in Thailand cover approximately 8.7 million ha or 30 percent of the total global area of natural teak forests.

Only fragments of the original teak forests remain at present, mainly in a few national parks and wildlife sanctuaries. Teak has been planted in Thailand on a large scale since the 1960s to substitute the rapid decline of natural teak forests and to support domestic and international demands. This chapter aims to provide an understanding of natural teak forest management, teak plantations in Thailand, and examine the main gaps in sustainable teak forest management, as well as provide key recommendations

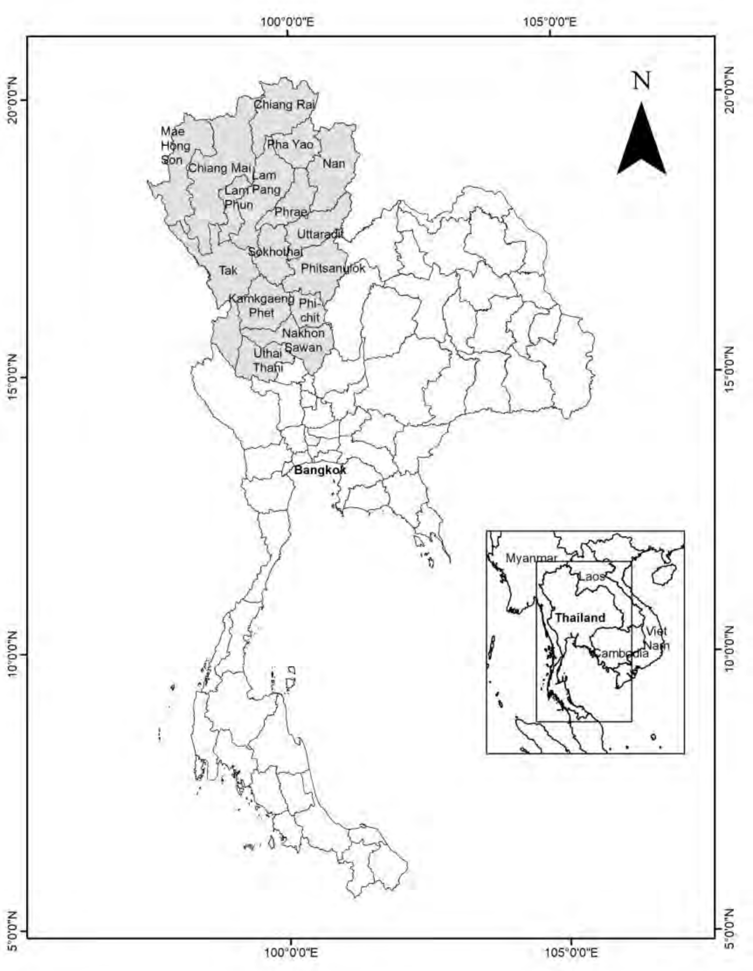


Figure 2-1 Thai Provinces with natural teak forests

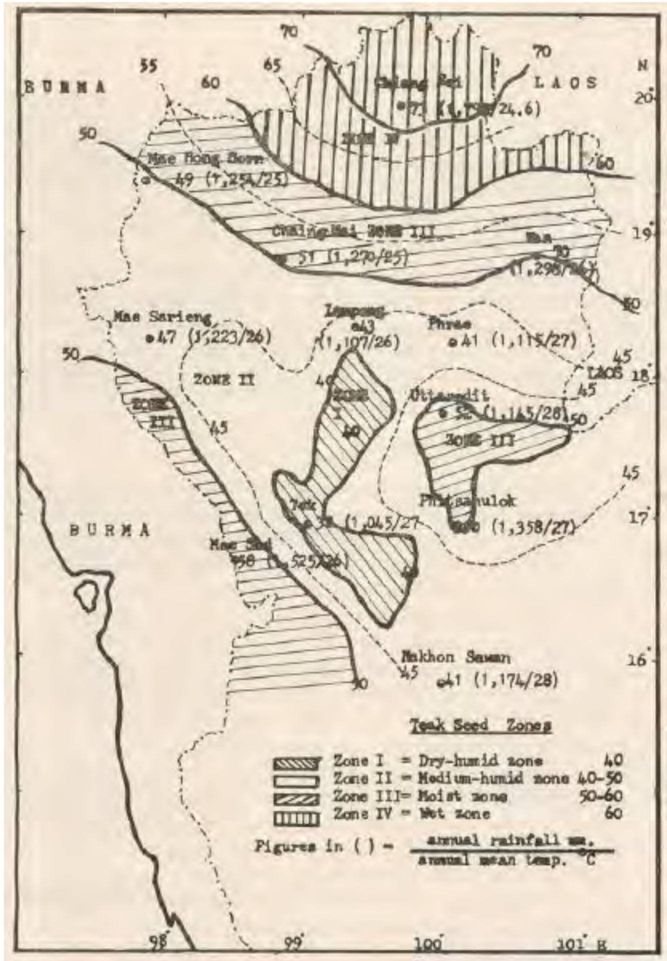


Figure 2-2 Natural teak zonation in Thailand
Source: Kaosa-ard (1979)

Status of Teak Forest in Thailand

As mentioned earlier, teak occurs naturally throughout the 17 provinces in northern Thailand covering an area of approximately 170,000 km^2 or 33% of the country's land area (Figure 2-1). However, it is confined in the hilly or mountainous region of Mae Hong Son, Chiang Mai, Chiang Rai, Payao, Lamphun, Lampang, Phrae, Nan, Tak, Sukhothai, Uttaradit, Phitsanulok and Kamphaneng Phet provinces. It was estimated that the teak bearing forests covered approximately 30,000 km^2 (Banijbhana, 1957).

Teak occurs naturally in a wide range of climatic conditions from dry areas with only 500 mm annual rainfall up to the areas with 5,000 mm annual rainfall. However, optimum conditions of teak are in the areas between 1,200 m and 2,500 mm annual rainfall (Kaosa-ard, 1989). It requires a dry period of 3-5 months for the production of good timber, but it usually avoids both extreme dry and moist locations. Teak can be grown in areas with 75-90% sunlight (Troup, 1921; Kermode, 1957; Kadambi, 1972). The tolerance range of mean temperatures lies between 15°C to 40°C, but the optimal temperature ranges from 25°C to 35°C with the optimum annual precipitation between 500 – 3,500 mm (Kaosa-ard, 1989). In addition, it shows better performances on nutrient-rich, deep-well drained, sandy-loamy to clay-loamy soils (Kaosa-ard, 1995) originated from limestone, schist, gneiss, shale (Kulkarni, 1951; Kaosa-ard, 1981) and pH 5.5 to 6.5 (Seth & Yadav, 1959; Kaosa-ard, 1989; Tewari, 1992). Under these conditions, the annual increment of teak is approximately 2 – 15 m^3/ha/yr (FAO, 1956; White, 1991). Kaosa-ard (1979) classified natural teak forests in Thailand into 4 zones (Figure 2-2) using the P:T ratio moisture index method, where P is annual rainfall in mm, and T is annual mean temperature as follows:

Zone 1: dry-humid zone with the P/T ratio smaller than 40,

Zone 2: medium-humid zone with P/T ratio of 40-50,

Zone 3: moist-humid zone with P/T ratio of 50-60, and

Zone 4: wet zone with P/T ratio of greater than 60.

Northern Thailand is recognized as the home of teak in Thailand. Long-term forest monitoring (RFD, 2020) reported that forest cover in this region rapidly declined from 68 to 43% from 1961 to 1998 (Figure 2-3) except in protected areas, due to extensive logging in the past and the expansion of agricultural land. It should be noted that the new assessment showed that forest cover in the year 2000 was 56% (an increase of 13%) (DNP, 2000). However, the 2000 data might not be representative of future trends because it was obtained by a different method of interpretation with higher image resolution (Trisurat, 2007). In addition, the forest cover from 2000 to 2020 still indicated a steady decline of forest cover in the north. The Northern region is dominated by mixed deciduous forests (66%) and followed by evergreen forest (21%), dry dipterocarp (10%), while pine forest and scrub are rare (DNP, 2000).

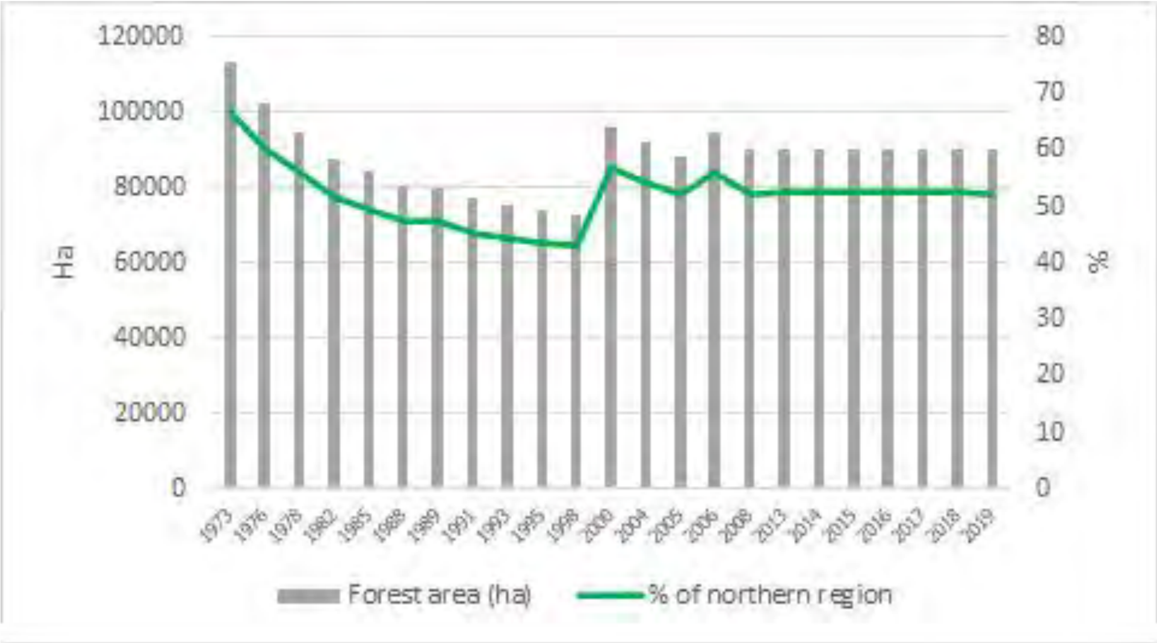


Figure 2-3 Forest area in northern Thailand (Source: Forest Statistics Report 1973-2020)

Teak Forest Management before Logging Ban in 1989

Before the establishment of the RFD in 1896, teak forests in the north were private properties of the Chiefs or Community Leaders. Any person (mainly Chinese and Burmese merchants) who wished to exploit teak had to obtain permission and pay certain fees in exchange. Commercial teak exploitation was started in 1864 (RFD, 2013) by three major foreign companies, namely, Borneo Co., Anglo-Thai Co., and Bombay Burma Co. There were no regulations to control timber harvesting and the right to exploit forest areas was vested with the ruler of each city (Banjibhana, 1957). Later, some controls on teak felling were introduced by the Thai (Siam Government) under the Treaty of 1893 with Britain. However, granting permission to foreign companies resulted in dispute and complaints from small companies and individuals; these issues were brought to the government to mediate and settle the conflicts.

The Royal Forest Department (RFD) was established in 1886 mainly to operate teak concessions in a systematic way. The Government (RFD) took control of teak ownership from the Chiefs or Community Leaders and reduced the teak lease period from 100 years to 12 years and divided into two 6-year concession blocks and the contractor allowed to work only in one half for 6 years. In 1908, it was changed to 30 years and divided into 2 block periods.

In 1960, the Working Plan for Mae Ngao Forest B.E. 2505-14 (1961-70) was proposed by Champion (1968). This comprehensive plan with more modernized and intensive management was implemented in 1964. In addition, Brandis silvicultural system or "Modified Selection System" was applied. Forest trees below the specified girth limits was not allowed to cut. The girth limit at 1.3 m height level was 213 cm in the beginning, then changed to 190 cm during the 80's before being increased to 220 cm. The Brandis method was stopped because yields were low and fluctuating, and then selection felling was adopted by girth limit.

Paosajja (1992) reported that average annual teak wood production from natural forests and plantations during 1962-1971 was 209,327 m^3, reduced to less than 100,000 m^3 in 1980, and further 50,000 m^3 in 1984. In addition, the teak yield from natural forest concessions in the north in 1985 was only one-tenth that in 1971 (Gajaseni & Jordan, 1990). Teak wood production was not sufficient for domestic consumption and reprocessing for export since 1980, therefore it has been substituted by imported wood.

Thai forest manufacturing industry has responded to the national logging ban in 1989 by shifting into imported wood materials and utilizing less valuable plantation species grown by smallholder and contracted farmers, particularly rubberwood. Currently, teak logging work is allowed only in teak plantations by the Forestry Industry Organization (FIO). However, the demand of wood in Thailand is expected to increase from 66 million m^3 in 2005 to 128 million m^3 in 2027 to support national and international market (Faculty of Forestry, 2018) (Figure 2-4).

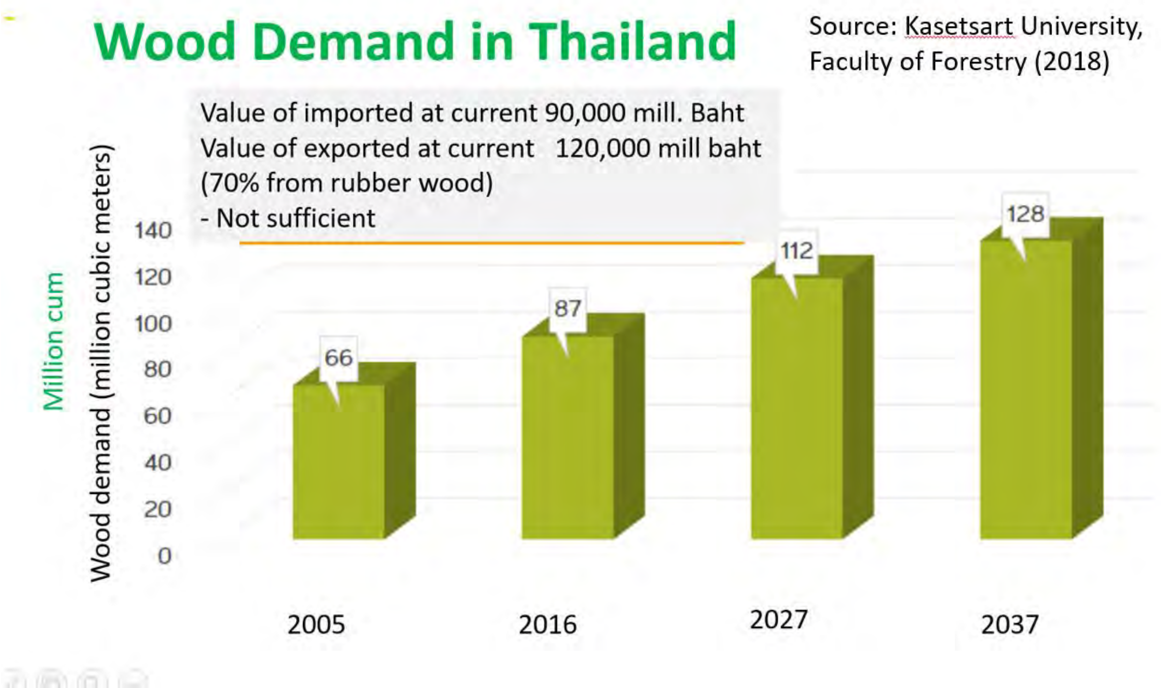


Figure 2-4 Thailand's wood demand to support national and international market

Teak Plantation in Thailand

The first teak plantation was established in the year 1906 at Denchai District, Phrae Province in northern Thailand using Taungya plantation model, a model that had yielded good results in Myanmar.

Previously, teak plantations were planted by dibbling teak seeds. The planting material changed from direct seeding to stump planting in 1935 after a successful trial in Mae Hong Son Province. Planting stock raised from tissue culture and cutting techniques were first planted out in the field in 1986 and 1995, respectively which later developed to planting by stumps (Thaiutsa, 2008). In early days, the goal of teak plantation was to replace those harvested from natural forest, not taking into account the good variety at all. Currently, the main management objectives of forest plantations in general, especially teak can be classified into three categories: production, protection, and amenity. However, the primary objective of teak plantations is for commercial purpose to earn direct benefits, both from wood and non-wood products.

The Forest Industry Organization (FIO) is recognized as the main agency to implement commercial plantations, followed by the Thai Plywood Company (TPC), and several companies in the private sector. The FIO (established in 1933) and TPC (established in 1951 and closed in 2012) are state enterprises that began to grow teak in 1968. FIO was earlier a section under the Logging Division of the RFD. It has been separated from RFD as an independent organization (now under the Ministry of Natural Resources and Environment) since 1956. The initial rotation period of teak was 60 years and later shortened to 30 years. Based on collective data from Graudal & Moestrup (2017), the total area of teak plantation in Thailand was ranked third (836,000 ha) after India (2.56 million ha), Indonesia (1.47 million ha) and contributes 12% of the total area of teak plantation (6.89 million ha). Of this the area planted by FIO was 99,200 ha (Patama Subwilai, personal communication). Most (86%) of the FIO's teak plantations are in the north.

The strength of teak from Thailand and Myanmar makes it widely known throughout the world as golden teak. However, the weak point of teak plantations in Thailand is low productivity compared to other countries. The highest mean annual increment (MAI) of teak planted on the best site on a 50-year rotation was recorded in Indonesia, followed by Myanmar, India and Thailand. (Table 2-1).

Table 2-1 Mean annual increment of 50-year rotation of planted teak on the best sites within its natural ranges

Country	MAI (m3/ha/year)	Source
Indonesia	17.81	FAO (2001)
Myanmar	12.00	FAO (2001)
India	10.00	FAO (2001)
Thailand (under bark)	4.69	Chanpaisaeng (1977)
Thailand (over bark)	5.94	Suraphapmaitri (1985)

Compiled by Thaiutsa (2008)

Annual increment of teak plantation is largely dependent on-site quality and the silvicultural practices adopted. Chanpaisaeng (1977) indicated that teak planted on good sites can get yields of 143.56 m^3/ha within 20 years, but it would take 30 years to get yields of 140 m^3/ha on medium sites, and 50 years for 142.44 m^3/ha on poor sites. Teak improvement in Thailand has been carried out since 1957 at the Faculty of Forestry, Kasetsart University. Later, the first Teak improvement Center in Lampang Province was established in 1965 with the technical and financial support of Danish International Development Agency (DANIDA). For over 50 years, the results showed progress in genetic improvement and resulted in improved teak varieties, which grow faster, produce good quality wood, and resist pests and diseases. In addition, the knowledge on teak improvement program has been developed, such as development of cutting techniques, pollination technique, use of molecular technology and use of Index selection together with Forward selection in offspring test to establish the seed production areas which lead to modern breeding strategy with high accuracy and efficiency.

Photo 2-2 A mother teak tree from Paa Sak Nawamindra Rachinee forest, Mae Hong Son Province

Photo 2-3 Seedling production from good quality material

Teak's Import and Export

The annual wood increment of planted teak forests alone is estimated at around 30 million m^3 but only 1.5 to 2 million m^3 are reported to be harvested from these plantations annually besides 0.5 million m^3 harvested from natural forests predominantly from Myanmar. Rest of teak comes either from illegal logging in natural forests or unrecorded harvesting by small farmers and local communities. India, Indonesia and Myanmar contribute more than 90% of teak production. The production of teak from natural forests in India, Lao PDR, Myanmar, and Thailand is low as most of their natural teak forests grow within protected areas. In addition, Thailand imposed a nationwide logging ban in 1989, while Myanmar also has enforced the log export ban since 1 April 2014 (Brown & Koller, 2017).

The RFD reported that teak production in Thailand mainly harvested from FIO's plantations ranges from 54,000-60,000 m^3 annually. Therefore, the production is not sufficient to meet domestic consumption and export. Thailand has imported teak logs and sawn-teak timber since 1957. The imported volume increased from 10,000 m^3 in 1957 to 30,820 m^3 in 1989, and 291,761 m^3 in 1991 largely from Myanmar as a result of the logging ban in 1989. Paosajja (1992) estimated that the annual demand for teak wood was around 300,000 m^3.

In the last decade, the global annual trade of teak roundwood was more than 1 million m^3 with a value of USD 487 million a year. The global demand for teak is expected to grow at a high rate, especially from planted teak. This is due to the shortage of native teak supplies to meet the demand, while population incomes and domestic demand in major consumer countries such as India and China are steadily rising. The three major importing countries were India, importing three quarters (74%), followed by Thailand (16%) and China (10%). Teak imports to Thailand have substantially declined in recent years, from a peak of 340,816 m^3 in 2002 (90 million USD) to 41,243 m^3 in 2010, and only 6,194 m^3 in 2020 (8.3 million USD) (RFD Statistics Report) (Figure 2-5). On the other hand, China and India have increased their import volumes.

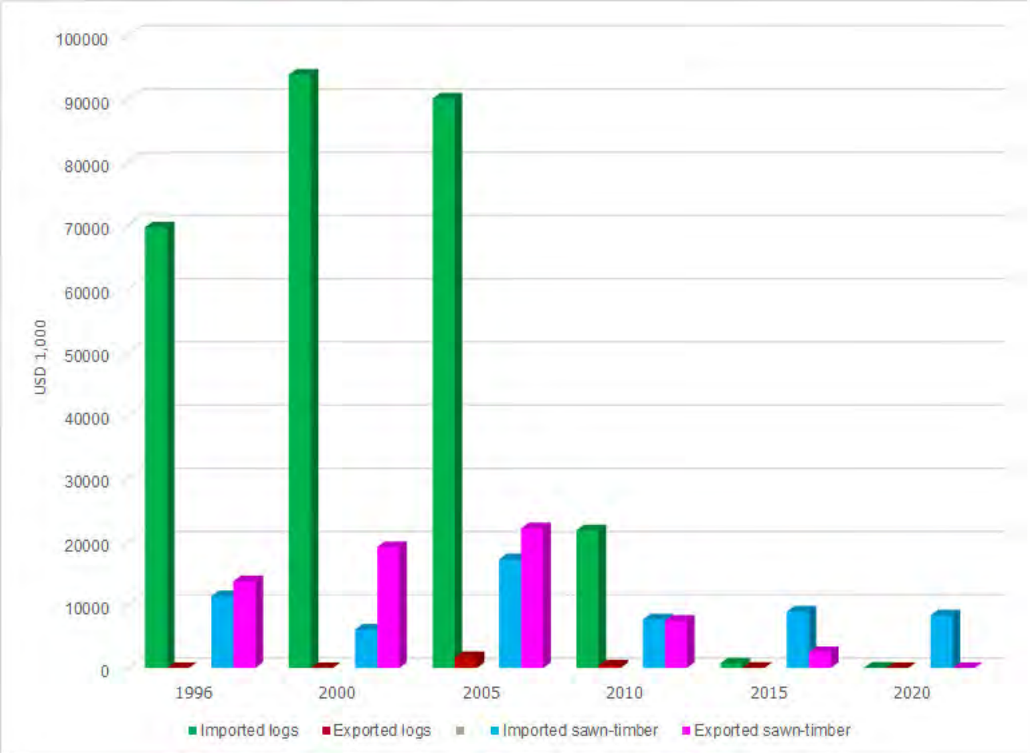


Figure 2-5 Value of import and export of teak logs and sawn-teak timber

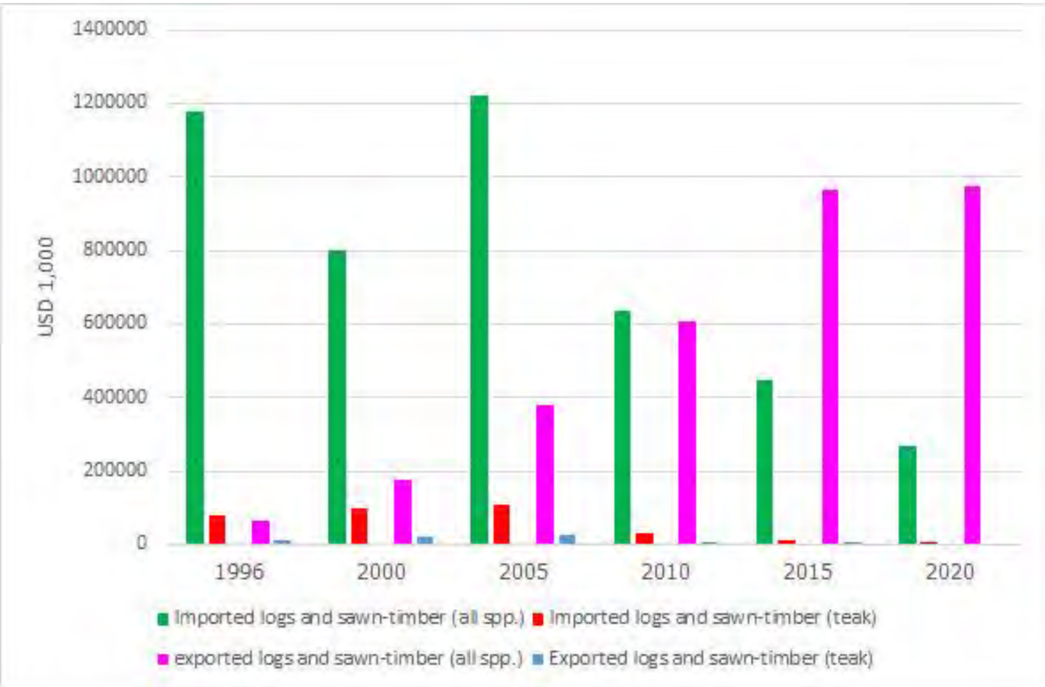


Figure 2-6 Value of import and export of timbers (all species) and teak
Source: Forestry Statistics Report (RFD, 1996-2020)

In addition, the values of exported teak logs and sawn-teak wood declined from 19 million USD in 2000 to less than 2 million USD in 2015, and no export in 2020 (Figure 2-6). Export of teak logs and sawn-timber in the form of re-exports by private sectors has been suspended since 1991. Teak is allowed to be exported only as knock-down furniture or veneer wood. Only FIO is allowed to export certified teak timber (Photo 2-4). Moreover, the export tax is set at 40% of the exported value, which acts as a deterrence. Teak log and lumber are imported as raw materials for export products such as fiberboard, plywood, flooring panels, and wooden furniture. The values of exported wood products have increased steadily from 174 million USD in 2000 to 605 USD in 2010 and 974 million USD in 2020 (RFD Statistics Report). The main partners of Thailand are China, Hong Kong, the United States, Japan, Malaysia and Singapore.

Photo 2-4 Teak timbers in the log yard at the Forest Industry Organization (FIO)

Laws and Regulations Related to Teak

Important laws and regulations related to teak include Forest Act, B.E. 2484 (B.C. 1941) amended in 2019 that is related to permission of harvesting, moving or transporting and utilizing process (wood processing, establishment of wood processing mill, and trading). In the past, due to the strict forest laws' enforcement for cutting and removal, teak wherever it grows in the country is classified as a restricted species causing people to have no motives to plant because they cannot cut and sold. To solve this problem, RFD had tried to amend the forest law to facilitate and incentivize people to grow more trees to increase green areas and help increase the economy of the country via timber trade. The new Forest Act of 2019 withdraws the status of teak from restricted species to economic species. This amended Act regulates tree species (including teak) planted in legal and ownership (private land) can be cut but the owner still requires permission from the RFD for transportation.

Besides, the Forest Plantation Act, B.E. 2535 encourages people to register for forest plantation, registration for the plantation seal, and to facilitate the issuance of a tree felling certificate, timber processing, transporting and utilizing following the Forest Act of 2019. According to the cabinet resolution on January 11, 2000, only Forest Industry Organization (FIO) was allowed to export teak outside the Kingdom of Thailand but now, with the anticipated boost in timber trade, the monopoly of the Forest Industry Organization on teak export has been removed.

National Forest Policies 2019 had set the target of forest area throughout the country to be at least 40 percent of the country's land area and classified 25% for conservation forestry and the rest 15% forests for economic returns. Together with Article 7 of the amended Forest Act of 2019, no tree growing on land with ownership or possession rights under the Code Land Law are classified restricted. This is expected to encourage and incentivize people to grow more trees. Since teak is a preferred species by private planters, both small and large, it is expected that the area of teak plantations in Thailand will dramatically increase in the near future.

Besides teak plantations, most of the natural teak forests are found in protected areas such as national parks and wildlife sanctuaries. The Thai Government has established protected areas system covering about 22% of the country land area (DNP, 2021). Therefore, it is most likely that natural teak forests are well protected.

Main Gaps

Data availability

The RFD is the main agency to generate and collate data within the overall forest data on private plantations and public plantations (RFD & FIO), and data on domestic production or wood utilization in factories. Data on the value of imports and exports is available in a timely manner in great detail. However, data on domestic plantation resources, production, overall wood demands and supply is rather limited.

Species exemptions from regulations

Although article 7 of the amended Forest Act 2019 exempts some species (especially teak) planted in the legal ownership (private land), and recognizes as commercial timber species like eucalyptus and rubberwood, timber owners still require permission from the RFD for transportation of felled timber for processing. It becomes the main issue created from laws and regulations. Under current regulations, there are no simple means for users of these species to document legality unless a voluntary Certificate of Origin is sought from the RFD.

Certification scheme

The major challenge for teak growers is to produce quality wood that is acceptable in international markets and to establish legal and sustainable wood supply chains while improving national economy and local communities' livelihood. Thailand's voluntary certification scheme is a means to give Thai industry a method to show to the buyers the legal origin of wood they are purchasing. However, with the complexity of the industry, high cost (particular smallholders), only a few big companies and FIO can afford the certification scheme. It makes it difficult for a significant part of Thai wood industry to provide detailed information on timber sources of supply to buyers.

Low-quality material: Teak improvement in Thailand has been practiced over 50 years to facilitate genetic improvement and grow improved teak varieties which grow faster, produce good quality teakwood and resist pests and diseases. Most of the teak plantations either by the RFD, private sectors and stallholders still use seedlings from unknown seed sources. As the rotation period of teak is 30 years and it requires long-term investments, good quality planting material and proper silvicultural practices are quite essential.

Main Recommendations

Establish computerized system

Gather and develop systematic data collection and computer-based system of domestic markets and wood products showing annual domestic production of teak and sources of supply as well as import and export data to make policy recommendations.

Facilitate wood utilization

According to the National Policy, Thailand is aiming to increase production forests from the current 8.2% of the country to 15%. It is necessary to implement a comprehensive teak plantation program focusing on both the public and private sectors. To facilitate the planting of teak and other tree species by the private sector, Thai government had amended the Forest Act in 2019 to remove restrictions that hinder the development of private teak plantations. Moreover, it also increases economic and environmental benefits for the country and conserve teak, a plant of national value, to be sustainable and last forever.

Proof of legality

Thailand's timber industry needs to prepare data on international trade and domestic consumption. Accurate information on species of wood, sources and legality is required. To achieve this, a number of measures should be discussed: Teak timber and wood products that are exported to international markets would benefit from having a Certificate of Origin (CoO) and other documentation that confirms the legality of harvest in the country of origin. This will require coordination with countries exporting wood and timber to Thailand. In addition, teak for domestic consumption mainly produced by smallholders should have national certification. ITTO/RFD used to document CI & CoC scheme. This document and process should be authorized by the RFD. The private sector will need to develop and install chain of custody systems in their factories and mills.

Use quality planting material

The government (RFD) should increase capacity and promote smallholders to use good quality material for establishing plantations. In addition, the next approach to teak improvement program in Thailand is recommended as follows; 1) Develop strategies for teak improvement program in line with new technologies and accelerate the development of breeding in the 2^{nd} generation including the development of cross-breeding among origin in order to get good breeds with high genetic diversity to be selected in the next generation, 2) Increase capacity building for personnel in teak breeding by encouraging the exchange of expertise and personnel between institutions and countries and international cooperation with various organizations and 3) Promote research on wood quality improvement.

Conclusion

In Thailand, teak in natural forests is on decline but since 1993 teak in forest plantation is increasing and will rapidly increase in the coming years after the new amendment of Forest Act 2019 that allows all regulated tree species including teak planted in private land to be cut and sold. This will facilitate and incentivize people to grow more trees to increase green areas and help to increase the country's economy via timber trade. The Government's role should also be transformed from regulator to facilitator. To achieve teak trade in the future, some outdated forest policy needs to be revised. For the long-term investment of teak plantations, genetically improved planting materials and vegetative propagation techniques need to be improved to increase the productivity of teak plantations. Finally, for sustainable teak plantation management, legal source and supply chain control need to be strictly enforced to obtain legal teak timber products to support sustainable global market.

References

Banijbhana, D. (1957). Teak forests of Thailand. In: *Tropical Silvilculture,* 2, 193-205. FAO, Rome.

Brown, H. & Koller, W. (2017). Financial Appraisal of Planted Teak Forest Investments. *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources. IUFRO World Series, 36*, 90-94.

Champion, H. G. & Seth, S.K. 1968. *A Revised Survey of the Forest Types of India:*113-117, 181- 184. Manager of Publications, Delhi.

Chanpaisaeng, S. (1977). *Yield of Teak Plantation*. MSc. thesis, Kasetsart University, Bangkok, Thailand. 97 p. (in Thai with English abstract).

DNP. (2000). *Forest Resource Utilization Map 2000*. Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand.

DNP. (2021). *Report on Status of Natural Teak Forest in Thailand during 2006-2020*. Forest Inventory and Assessment Division Forest and Plant Conservation Research Office, Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand.

Faculty of Forestry. (2018). *Strategy and Action Plan for Extension of Integrated Economic Trees (2018-2036)*. Final Report Submitted to the Royal Forest Department. Kasetsart University, Bangkok, Thailand.

FAO. (1956). *Report of the First session of the Teak Sub-Commission*. Bangkok, Thailand, 9-18 February 1956.

FAO (2001). *The Global Forest Resources Assessment 2000 Summary Report*. Committee on Forestry. Available Source: www.fao.org/docrep/meeting/003/x9835e00.html#P469 24024, March 16, 2001.

Royal Forest Department (RFD). (2021). *Forestry Statistics Data, 2021*. Ministry of Natural Resources and Environment. Thailand. Bangkok, Thailand, 168 p.

Gajaseni, J. & Jordan, C. F. (1990). Decline of teak yield in northern Thailand: effects of selective logging on forest structure. *Biotropica*, 114-118.

Graudal, L. & Moestrup, S. (2017). The genetic variation in natural and planted teak forests: Characterisation, use and conservation for the future. In *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources* (eds., W. Kollert, & M. Kleine), pp. 19-29. International Union of Forest Research Organizations (IUFRO). IUFRO world series Vol. 36 http://www.iufro.org/publications/series/worldseries/article/2017/06/21/world-series-vol-36-the-global-teak-study-analysis-evaluation-and-future-potential-of-teak-reso/

Kadambi, K. (1972). *Silviculture and Management of Teak*. Austin State University, Texas, School of Forestry, *Bulletin, 24*, 37.

Kaosa-ard, A. (1979). *Teak Seed Center. Annual Report No. 1*. Teak Seed Center, Ngao, Lampang, Thailand, 35 p.

Kaosa-ard, A. (1989). Teak (*Tectona grandis* L.f.) its natural distribution and related factors. *Natural History Bulletin of the Siam Society, 29*, 55-74.

Kaosa-ard, A. (1995). Management of teak plantations: Overview of problems in teak plantation establishment. Teak for future. In: *Proceedings of the Second Regional Seminar on Teak. 29May-3 June 1995*, pp. 49-59. TEAKNET Publication No.1, RAP Publication 1998/5, Yangon, Myanmar.

Kermode, C.W.D. (1957). *Teak*. Tropical Silviculture, 2, 168-178. FAO, Rome.

Kollert, W.& Cherubini, L. (2012). *Teak resources and market assessment*. Planted Forests and Trees Working Paper FP/47/E. Edited by Food and Agriculture Organization of the United Nations. Rome. Available online at http://www.fao.org/3/an537e/an537e00.pdf, checked on 5/3/2021.

Kulkarni, D.H. (1951). Distribution of teak (*Tectona grandis* L.f.) on the northern slopes of the Satpuras with special relation to geology, pp. 254-263. In: *Proc. 8th Silviculture Conference*, Dehra Dun, India.

Mahaphol, S. (1954). *Teak in Thailand*. Royal Forest Department. Ministry of Agriculture, Paper No. R.16, 30 p.

Pandey, D. & Brown, C. (2000). Teak: a global overview. An overview of global teak resources and issues affecting their future outlook. *Unasylva, 51*(201), 3–13.

Paosajja, R. (1992). Economic forest. In: *Forest Research Center, Forest Resource Development, Faculty of Forestry*, pp.92-110. Kasetsart University, Bangkok, Thailand.

Pumijumnong, N. (1995). *Dendrochrnologie mit Teak* (*Tectona grandis* L.) *in Nord-Thailand*. Dissertation, University Hamburg, Germany.

RFD (Royal Forest Department). (2013). *Thai Teak Knowledge*. Thailand's Agriculture and Co-operatives Printing Ltd, Bangkok. Thailand. 302 p.

RFD (Royal Forest Department). (2020). *Forest Statistics Data 2020*. Royal Forest Department, Thailand.

Seth, S. K. & Yadav, J. S. P. (1959). Teak soils. *Indian Forester,* 85, 2-16.

Suraphapmaitri, S. (1985). *Site Index and Yield of Teak Plantation in Lampang Province*. Special Problem. Department of Silviculture, Kasetsart University, Bangkok. Thailand. 49 p. (in Thai with English abstract)

Tewari, D.N. (1992). *A monograph on teak* (*Tectona grandis* Linn. f.). International Book Distributers, Dehra Dun, India. 479 p.

Thaiuta, B. (1992). Commercial Plantation in Thailand: A Case Study of the Forest Industry Organization. In *Proceedings of the FORTROP II: Tropical Forestry Change in a Changing World, 17-20 November 2008*, pp. 67-83. Kasetsart University, Bangkok, Thailand.

Trisurat, Y. (2007). Applying gap analysis and a comparison index to assess protected areas in Thailand. *Environmental Management,* 39, 235-245.

Troup, R. S. (1921). *The Silviculture of Indian Trees.* Vol. 2. Oxford University Press. 300 p.

White, K. J. (1991). *Teak, some aspects of research and development*. RAPA Publication 1991/17. FAO Regional Office for Asia and the Pacific, FAO, Bangkok. 69 p.

Chapter 3: Natural Teak Forests and Teak Plantations in Myanmar

Zar Chi Hlaing

Abstract

Teak is one of the most important hardwood valuable species that is being planted extensively in several countries in the Asia-Pacific region. Being indigenous to the region, substantial experience has been gained in the management of natural and man-made stands of teak. The reasons for the relatively wide use of teak, where quality hardwoods are planted, are its ease of propagation, establishment and management, as well as its excellent wood quality. It is also one of the most valuable multi-purpose timbers of the world. In Myanmar, natural teak forests have been managed for many years with sustained timber production as the primary objective. Myanmar is the only country producing large teak logs from natural forest, which attract a price advantage compared with small logs from plantations and which is likely to continue in the foreseeable future. The forest resources of Myanmar scientifically managed since 1856 have been decreasing due to population pressure and rising demands for forest lands and products. Myanmar's forests vary in species composition and stand structure, and constitute a valuable ecosystem due to their wide extent, varied topography and different climatic conditions. Myanmar is endowed with a forest covered area of 42.19% of the country's total land area that shows Myanmar position as one of the highest in the Asia-Pacific Region. Myanmar Selection System or MSS in short, has been the principal forest management system applied in managing the natural forests in Myanmar since 1856. Moreover, the extensive teak plantations were established in the 1970s, and a further large-scale plantation program was launched commencing from 1980. Teak plantations will be formed only on locations with site quality II/III and better.

Introduction

Teak (*Tectona grandis* L.f), is a species of worldwide reputation as paragon among timber trees belongs to the family Lamiaceae and is distributed predominantly in tropical and subtropical regions. Teak is one of the most important hardwood valuable species planted extensively in several countries in the Asia-Pacific region. Being indigenous to the region, substantial experience has been gained in the management of natural and man-made stands of teak. The reasons for the relatively wide use of teak, where quality hardwoods are planted, are its ease of propagation, establishment and management, as well as its excellent wood quality. It is also one of the most valuable multi-purpose timbers of the world. It is indigenous to only four countries in South and South-East Asia, and dense natural forests with big and beautiful admiralty quality teak have degraded and shrunk so rapidly that at present they are confined only to Myanmar and to some extent to India (Gyi & Tint, 1998).

Even though teak once covered a large percentage of India, Thailand and Myanmar and a small area of Laos, there is now very restricted distribution in each of these countries except Myanmar. In Myanmar, natural teak forests have been managed for many years with sustained timber production as the primary object. Myanmar is the only country producing large teak logs from natural forest, which attract a price advantage compared with small logs from plantations and which is likely to continue in the foreseeable future. However, the area and quality of teak forests are declining with the increasing population and greater pressure on forested land for conversion to agricultural land and illicit cutting. Forest resources, though scientifically managed since 1856, have been decreasing gradually both in extend and quality due to increased population pressure and consequent rising demands for timber for domestic and foreign uses. Annual production of teak is estimated to be about 450,000 m3 (1991-2000 average) decreased to 230,000 m3 (2000-2011 average), in the form of logs and sawn timbers, of which are mostly from natural forests. From forestry sector, the total foreign exchange earning of Myanmar comes from export of timber (Soe, 2009), about 90 % of which is derived from teak (Kyaw, 2003). Although there were plenty of teak trees in the natural forests, in Myanmar, in various densities, teak plantations were established in a compensatory way up to 1962. In Myanmar, extensive teak plantations were formed in the 1970s, and a further large-scale plantation program was launched commencing from 1980. It started with an annual target of 6,200 ha, increasing gradually. The Forest Department (FD) of Myanmar launched a special teak plantation program in early 1998 in addition to the existing teak plantation scheme. The special program is incorporated with major reforms placing emphasis primarily on increased timber production and on overcoming the environmental constraints experienced by forest plantations. The special teak plantation program would, therefore, lead to the establishment of teak plantations over an area of 324,000 ha at the end of the 40-year rotation. A sustainable production of 572,000 m3 to 930,000 m^3 of teak is estimated to be available annual from 8,100 ha of these plantations by the end of the rotation. Teak plantations will be formed only on locations with site quality II/III and better.

In Myanmar there are four broad ecological zones namely: Moist Humid (Northern Hilly Region), Dry Humid (Eastern High Plateau), Moist (Southern Plain, Hill and Deltaic Area), and Dry (Central Plain). Teak plantations are mainly concentrated in the Bago Yoma Region, which falls in moist ecological zones, a well-known place of high-quality natural teak forests. The area of teak plantations established in 1998 had already reached 195,043 ha, constituting about 41% of the total area of all plantations established in Myanmar.

Forest Resources

Possessing a great variation of forest ecoregions, there are six major forest types in Myanmar. Areas of respective forest types are shown in Figure 3-1 and Table 3-1. The majority of the forest area is covered by mixed deciduous forest, and hill and temperate evergreen forests, accounting for 38.20 and 26.92%, respectively.

Table 3-1 Area of major forest types in Myanmar in 2020

No.	Major forest types	Area (ha)	% of forested area
1.	Mangrove Forest	325,259.20	1.12
2.	Tropical Evergreen Forest	5,024,093.00	17.30
3.	Mixed Deciduous Forest	11,093,662.00	38.20
4.	Dry Forest	2,904,100.00	10.00
5.	Deciduous Dipterocarp	1,237,146.60	4.26
6.	Hill and Temperate Evergreen	7,817,837.20	26.92
7.	Scrub and Grass Land	638,902.00	2.20
	Total Forest Area	**29,041,000.00**	**100.00**

Source: Forest Department (2020)

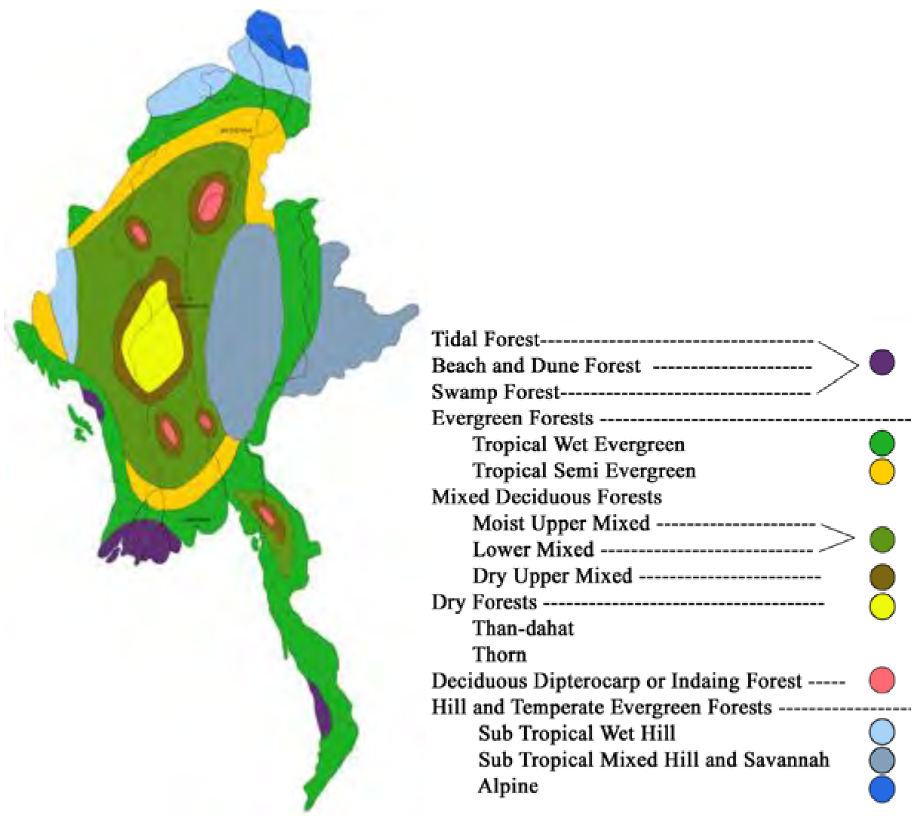


Figure 3-1 Major Forest types in Myanmar
Source: Armstrong (2004)

The Forest Resource Assessment (FRA 2020) conducted by the Food and Agriculture Organization of the United Nations (FAO) in cooperation with the Myanmar Forest Department has indicated that Myanmar is still endowed with a forest covered area of 42.19% of the country's land total area, one of the highest in the Asia-Pacific region. The status of forest cover is shown in Table 3-2.

Table 3-2 Forest cover status of Myanmar

Category	Area (1,000ha)	% of total country area
Closed Forest	11811.8	17.46
Open Forest	16283.61	24.07
Mangrove	448.4804	0.66
Sub-total (forest)	**28543.89**	**42.19**
Other Wooded lands	18756.05	27.72
Others	18386.8	27.18
Water	1971.14	2.91
Total	**67657.88**	**100**

Source: FRA (2020)

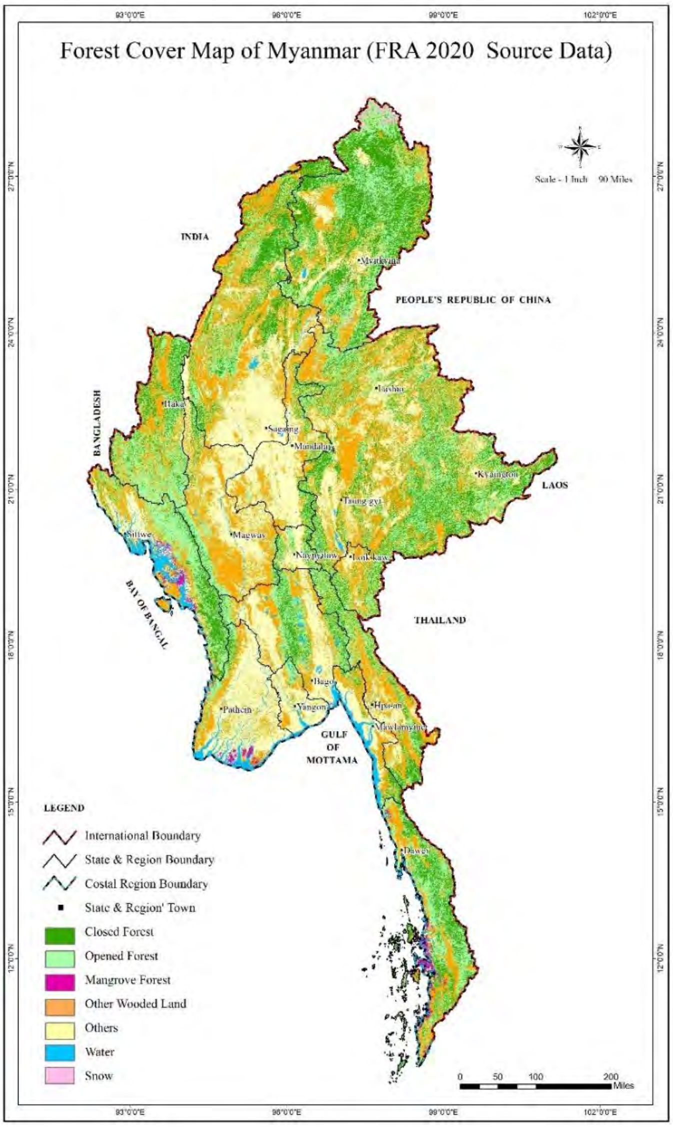


Figure 3-2 Forest cover of Myanmar

Table 3-3 Status of reserved forests, protected public forests and protected area system in Myanmar

Legal classification	Area (ha)	% of land area
Reserved forest (RF)	12,020,022.42	17.77
Protected public forest (PPF)	5,224,278.13	7.72
Total RF & PPF	17,244,300.55	25.49
Protected area (PAs)	3,959,320.11	5.85

Source: Forest Department (2020)

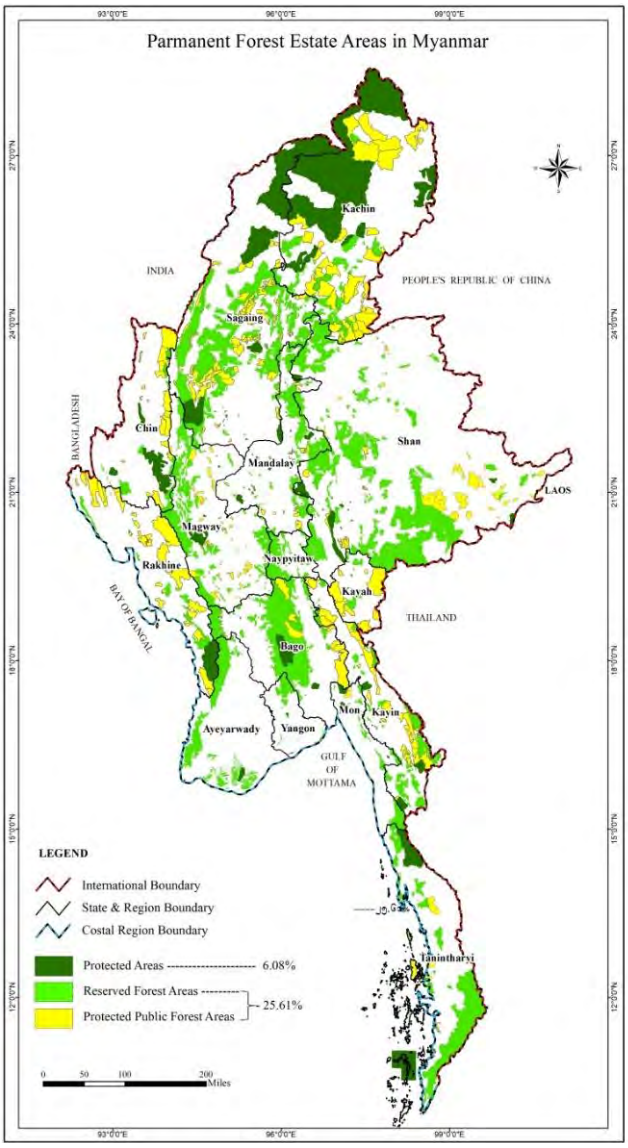


Figure 3-3 Permanent Forest Estate (PFE) Area in Myanmar
Source: Forest Department (2020)

Forests are owned by the State and are forest areas under the management of Forest Department can be categorized into two types legally as reserved forests (RF) and protected public forest (PPF) that collectively constitute the permanent forest estate (PFE), and that have been gazette through a legal process which contained 31.34% of total forested area and public forests or unclassified forests (68.66%) (Table 3-3 and Figure 3-3). RF is the best quality and higher commercial value forest, where the public have no harvesting rights. PPF is of lower commercial value, more accessible, where the public have some harvesting rights. Forest Department also designates protected areas (PAs) to preserve diverse ecosystems and species richness of Myanmar (Figure 3-3). The extent of PFE and Pas is shown in Table 3-3.

Natural Teak Forests

Tropical Myanmar in the Greater Mekong Sub-Region (GMS) is the only one country still maintaining large proportion of natural mixed deciduous forest which usually has teak, one of the most valuable premier woods, as the leading dominant species. These teak bearing forests managed under the Myanmar Selection System (MSS) since 1856 were once the main production sources for the world teak export. The forests in Myanmar are classified into six major forest types. Natural teak distribution occurs in the semi-evergreen forests, mixed deciduous forests and deciduous dipterocarp or Indaing forests (Table 3-1 and Figure 3-1).

Teak in the semi-evergreen forest is usually found as scattered individuals or in small groups with little or no regeneration present (Kermode, 1964). Trees are generally large and may be associated with *Michelia champaca, Tetrameles nudiflora, Dipterocarpus* species, Eugenia species, Cedrela species, etc. Undergrowth may consist of bamboo such as *Dendrocalamus hamiltonii* and *Cephalostachyum pergracile* and of small evergreen trees or shrubs.

In the lower mixed deciduous (LMD) forest, teak may be found gregariously or in patches. The species attains a large girth and height and trees are greatly fluted in these forests. Teak is usually found in association with *Anogeissus acuminata, Homalium tomentosum, Terminalia tomentosa*, etc. Bamboo is almost absent in this forest type.

The moist upper mixed deciduous (MUMD) forest produces teak with cleaner and straighter boles (Kermode, 1964). Here it is associated with *Xylia xylocarpus, Pterocarpus macrocarpus, Gmelina arborea, Bombax insignis*, etc. Bamboo species, such as *Bambusa polymorhpa* and *Cephalostachyum pergracile*, are found in this forest type. *Dendrocalamus hamiltonii* is also found in northern Myanmar.

The dry upper mixed deciduous (DUMD) forest produces teak of poorer quality than in the MUMD forests. Natural regeneration is frequent. In this forest type, teak is usually found associated with the same species as in MUMD forests with a few additional dry forest species, such as *Shorea obtusa, Pentacme siamensis* and Acacia catechu. Bamboos, as *Thyrostachys oliveri* in northern Myanmar and Dendrocalamus in the south, are also associated with teak in this forest type.

In Indaing (deciduous dipterocarp) forest, teak does not grow to a great size and is of poor quality. Regeneration is often abundant and the species is found in association with *Dipterocarpus tuberculatus* which may comprise as much as 80%, or more of the crop (Kermode, 1964). Semi-Indaing forests are usually found with an abundance of poor-quality teak. Regeneration is also profuse; teak grows mixed with *Pentacme siamensis* and *Shorea obtusa*.

Management of Teak Forest

The forest flora in Myanmar is diverse varying from sub-alpine in the north through dry and moist mixed deciduous to tropical rain forest species in the south. Teak, economically the most important forest resource of the country, is recognized as one of the most valued and sought after tropical timbers in the world and it is asserted that at present extensive and beautiful natural teak stands can be seen only in Myanmar. It has mainly been due to Myanmar's culture and affection attached towards the trees and the wildlife, the systematic management of which has already been exercised almost one and a half centuries now. In Myanmar, like in many other tropical countries, the forest resources are of paramount importance for national economic development and environmental conservation. The forests provide timber for both domestic use and export. They are also a vital source of food, shelter, fuel and income for the rural poor who constitute about 76% of the country's total population of over 55 million.

For management purposes the forests are assembled as the "working circles"; 1) teak selection working circle (TSWC); 2) non-teak hardwoods working circle (HSWC); and 3) local supply working circle (LSWC). The working circles are formed on the basis of accessibility and also on the nature and form of forest produce available. Occasionally, TSWC and HSWC overlap when non-teak hardwoods are also extracted in TSWC. Both working circles are worked under the Myanmar Selection System (MSS). The working circles consist of a group of reserves, which are further divided into felling series for the convenience of working according to the drainage and the geographical situation. Again, they are sub-divided into compartments on maps as well as on the ground; these are the basic management units. As for local supply reserves, annual coupes are the basic management units. They are similar to compartments, except that they are marked only on maps and are not permanently demarcated on the ground. Teak extraction is organized under the TSWC which includes all teak bearing forests.

Notwithstanding ever-increasing pressures on the forest resources for both domestic and export requirements, the forest management in Myanmar has always adhered to the principles of sustainable forest management (SFM). It is manifested by the wealth of the forest resources Myanmar is still endowed with. Myanmar Selection System, has been the principal forest management system applied in managing the natural forests in Myanmar since 1856. It involves adoption of a felling cycle of 30 years, prescription of exploitable sizes of trees, girdling of teak, selection making of other hardwoods, felling of less valuable trees interfering with the growth of teak, thinning of congested teak stands, enumeration of future yield trees down to fixed sizes, and fixing annual allowable cuts (AACs) for teak and other hardwoods. Simple coppice or coppice with standards systems are also applied in the local supply forest reserves.

Under MSS, only mature trees are selected and harvested. Harvesting of trees is regulated based on annual growth and controlled by girth limits prescribed species–wise. Felling of exploitable trees is within the bounds of carefully calculated Annual Allowable Cut (AAC). Fixing AACs, therefore, accords the increment of individual tree species, which has taken place over the course of 30-year felling cycle. AAC is thus a tool that ensures the harvest of timber yield on a sustained basis. AACs for teak and for non-teak other hardwoods are periodically revised and fixed based on the updated information. Annual yield is estimated as

$$AAC = ARR + \frac{\mathrm{CI} - \frac{1}{2}\, FC * ARR}{\mathrm{LP}}$$

where ARR = annual rate of recruitment of Class II trees to Class I; CI = original no. of trees in Class I; FC = felling cycle (i.e., 30 years); and LP = decided period to liquidate original CI trees (usually 60 years).

The MSS is not a true Selection system. It is a Stratified Uniform or Girth-limit system (Dawkins et al., 1998) by which all commercial species including teak above minimum felling girths are harvested at each felling cycle. The MSS has been being applied in Myanmar practically to all types of natural forests with virtually blanket silvicultural prescriptions, although it is well aware that silvicultural techniques are sometimes highly site-specific. Now, the unsuitability of the MSS is evidenced by the deteriorating stand structure, reduced growing stock and declining composition of teak, the principal species the whole management system of Myanmar virtually has been targeted (Kyaw, 2002). The extent of the natural teak forests is shrinking, the quality reducing and the yield dropping (FD, 2000). In light of this, the urgent need is obvious to either modify the MSS or to implement a gradual transformation method to convert the natural forests to the uniform system. For higher productivity and economics, the current status of the teak forests undoubtedly highlights the need for transformation. However, Myanmar Forest Policy (1995) has clearly stipulated not to substitute natural forests with plantations.

Until recent decade, forestry sector contributing about one third of the total country`s export timber trade had played a decisive role in the forest sector policy, and had exerted influence on the overall national politics. This traditional forest management regime and prescribed regulations, as time passed by need to be adjusted to cope with modern requirements including social and plantation forestry.

In recent years, there have been substantial changes in Myanmar forestry sector amidst the global forestry trend of climate change and carbon sequestration. A few remarkable changes include an introduction of log export ban (LEB), in April 2014, to promote local processing following logging ban policy in 2016, and modifying the MSS putting emphasis on bringing conservative silviculture into harmony with profitable exploitation on a sustainable basis. Furthermore, the 10-Year Myanmar Reforestation and Rehabilitation Programme (MRRP) launched in 2016 has stipulated a 10-year fallow period in the natural forests of the Bago Yomas Mountain range ("the home of teak"). The objective of the MRRP is to increase the forest cover by 5% within 10 years, by planting mainly teak and Pyinkado (Burmese ironwood, *Xylia xylocarpa*). In the rest of the country, the annual harvesting plan was set to harvest only 55% of teak and 33% of non-teak hardwood, respectively of the fixed annual yield. It is reported that, as a subsequent result, the supply of logs to the national and international markets has declined considerably. However, increased demand for timber, combined with reduced enforcement capacity and conflict in border areas, have caused illegal logging leading to loss and degradation of forests. Realizing the situation, the Ministry of Natural Resources and Environmental Conservation (MoNREC) is making significant efforts to restore sustainably managed forests through the legality programme like FLEGT (Forest Law Enforcement, Governance and Trade), MTLAS (Myanmar Timber Legality Assurance System), and other possible ways yet there are still limitations and restrictions for the control of illegal timber in the country.

Teak Plantations

Myanmar has a forest cover of about 33 million ha, which is almost half of its total land surface area in 1989. The forest cover consists mainly of natural forests, about 45 % of which are teak bearing forests. The forest resources, thought scientifically managed since 1856, have been decreasing gradually both in extent and quality due to increased population pressure and consequent rising demands for timber for domestic and foreign uses. Annual production of teak is estimated to be about 450,000 m3 (1991-2000 average) in the form of total foreign exchange earnings of Myanmar comes from export of timber, about 90% of which is derived from teak (Htun & Hlaing, 2001).

With a view to enriching the stocking in the natural teak bearing forests in Myanmar, teak plantations had been established in Paletwa area of the Chin State in about the year 1700 (FAO, 1956). The first attempt at teak plantations by Taungya method, which is world renowned today, was made in 1856 at Tharyawady in the Bago Region. However, plantations in those days were usually about 10 ha, with only one location exceeding 40 ha, and were established more with a view to increase the natural stock of teak rather than to create fully stocked stands. They were practiced to supplement or compensatory the natural regeneration of natural forest and, therefore, were called compensatory plantations. In this compensatory plantation concept, silvicultural treatment, particularly thinning, was done up to age of 40 years and plantations, after heavy thinning at this age, were treated as natural forests and placed under the improvement felling schedules.

After the establishment of the plantations in Tharyawady forest division in 1856 plantation forestry continued and a total of 310 ha had been attained by 1867-68, and a relatively large area of 1,370 ha was reached by 1876. Between 1880 and 1900 the area planted annually increased from 400 ha to over 1,620 ha and there was a more definite effort at creating full stack even-aged stands. Teak plantations established up to 1906 totaled about 24,282 ha. By the turn of the century, the unsystematic ways in which plantations had been formed became the subject of considerable criticism and in response to the proposal by the Chief Conservator of Forests in 1906 the Government imposed limitations on the establishment of plantations in favor of improvement felling in the natural forests.

After the First World War in 1918, the Taungya system was firmly established and ever since, and it became the standard practice in Myanmar plantation forestry. By 1920, more than 32,376 ha had been established with teak. In 1937-38, the Government revised the policy to establish 600 ha of plantations annually. The total area of plantations by 1940 was 56,130 ha. No progress was made in plantations afterwards, but rather, many were destroyed during the Second World War. After the war, scattered plantations were made to enrich teak stocking in annual planting rates of no more than 20 ha. Plantation establishment was curtailed during the period of insurrection from 1948-62 but resumed in 1964. In those days it was adequate to rely on natural forest management with compensatory planting without taking risk for a new venture on large scale plantation forestry.

Starting from early 1970s, block plantations were formed in the areas with degraded forests and poor stocking of teak and other valuable commercial species. As of 2000, 293,782 ha of Teak plantations had been established, i.e., 41% of total plantations formed in Myanmar. In early 1998, the Forest Department launched a special teak plantation program, which incorporates new features such as adoption of 40-year rotation, and management participation of interested and relevant communities. The adoption of a definite 40-year rotation reflects a significant deviation from the old concepts and final harvest will be made by clear cutting at the end of the rotation. The total teak plantations area is shown in Figure 3-4.

At present, the annual total plantation target for 1990-2010 has been fixed at around 361,807 ha of which commercial plantations constitute about 205,550 ha, representing 57 % of the total plantations. Amongst these commercial plantations, around 172,713 ha of Teak plantations have been established and 51 % of these teak plantations are being constructed under Special Teak Plantation Program, which was commenced in early 1998 at Bago Yoma Range. This special program has a defined rotation age of 40 years, and this program is, in fact, a national endeavor to maintain and increase the production of teak for both domestic and export markets with due consideration for social benefits and environmental restoration of degraded forests. With regards to establishing forest plantations, it is better noted that plantation forestry in Myanmar is not a substitute for natural forests management, supplementary as has been stipulated in the Myanmar Forest Policy, 1995 (Myint et al., 1999).

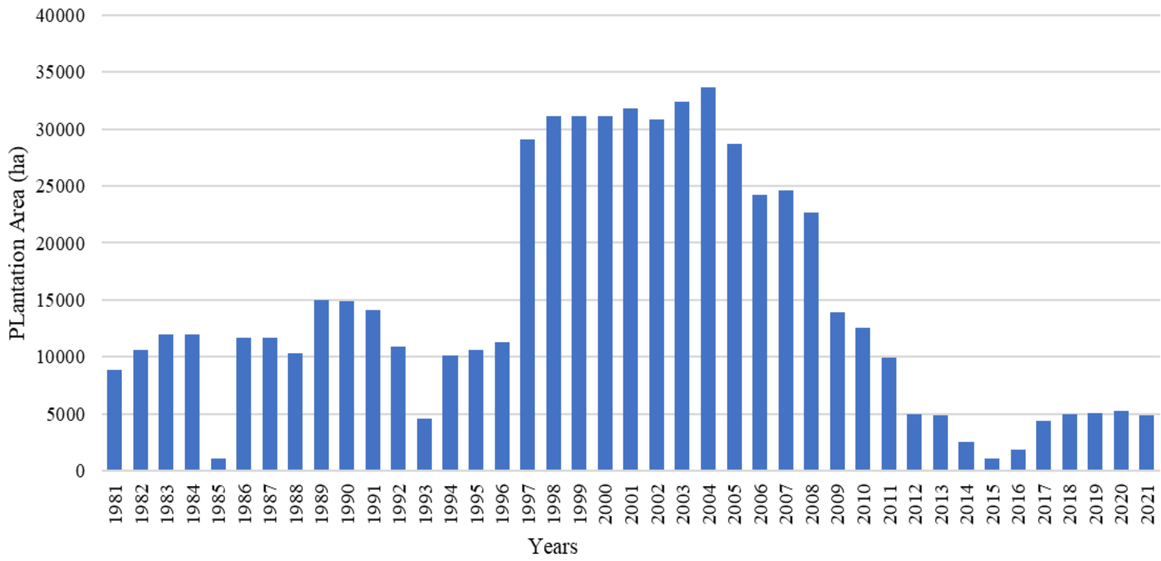


Figure 3-4 Established Teak plantations area (from 1981 to 2021)
Source: Haling (2012) and Forest Department (2021)

Teak Improvement in Myanmar

The conservation of forest species diversity including Teak was started in 1984. The major conservation of full stock of natural Teak forests and Teak plantation are into Seed Production Areas (SPAs), the establishment of Teak Hedge Gardens (THGs), Teak Clonal Seed Orchards (CSOs) and the Protected Area System (PAS). The conservation efforts in Myanmar are *in situ* based and concerned mainly with the protection of forests by the Forest Protection Law and Legislations.

In situ forest diversity conservation programmes and practices are as follow in Myanmar:

- Strengthening protected Area System (PAS) for Forest Genetic Resources,
- Enrichment planting, restoration and reforestation of degraded forests,
- Enhancement of seed production areas (SPA), and
- Selection and conservation of genetically good superior teak trees in the natural teak bearing forests

An important technique for long-term storage of genetic materials for further genetic improvement programme and sustainable development of species is *ex-situ* conservation.

Most of the rural community who depended on natural forest for their daily needs, they are more interested in utilization of forest resources than in conservation of forest genetic resources. For that reason, some level of *ex situ* conservation becomes important. The followings *ex situ* conservation activities are being conducted by the FD in Myanmar:

- Establishment of teak provenance trials to assess their variations by the locality
- Establishment of Teak Clonal Seed Orchard (CSO) and Teak Seedling Seed Orchard (SSO) to conserve superior germplasm
- Establishment of Teak Hedge Garden (THG) to collect superior material
- Planting of medicinal plants in Herbal Parks and Medicinal Plant Garden
- Tissue culture

Seed Production Areas

The planting with good quality seeds was conceived in Myanmar since the beginning of scientific forestry. The proper tree improvement program was greatly debated at the initiation of the East Pegu Yoma Project (EPP) in 1980's, and two clonal seed orchards (CSO) (Table 3-4) and some seed production areas (SPA) were established at that time (Gyi and Myint, 2008). In 1996, The Director of the Training and Research Development Division issued a detailed instruction on the establishment of SPA to the States and Regions. Until 2020, there are 6 species such as Teak, Pyinkado, Padauk, Yemane, Pinus and Mangrove species, with the total number of 235 (Table 3-5). But the proper conversion of plantations into SPA and the management strategies are still needed to effective and efficient successful SPA. Gyi and Myint (2008) mentioned that SPA establishment should be initiated as it is a quick and most inexpensive way of getting quality seed, and after that CSO can be followed with the expertise as it takes time and money.

Table 3-4 Teak clonal seed orchard in Myanmar

Established year	Area (ha)	Location
1981 -1982	34	Oktwin
1988	6	Pyinmana

Table 3-5 Seed production areas (SPA) in Myanmar

No.	Species	No. of SPAs	Area (ha)
1.	Teak (*Tectona grandis*)	191	3,256
2.	Pyinkado (*Xylia xylocarpa*)	27	768
3.	Padauk (*Pterocarpus marcrocarpus*)	1	10
4.	*Pinus sp.*	9	111
5.	Yemane (*Gemlina arborea*)	2	20
6.	6 Mangrove species	5	89
	Total	**235**	**4,254**

Teak Provenance Trials

Apart from the quantitative production of Teak plantation is quality. The improved planting materials of superior genetic quality is one of the factors for the successfully plantations establishment. The production of high-quality teak through the genetic improvement is the important role to support the sustainable forest management in Myanmar. As the ex-situ conservation of Teak, Teak provenance trials were established (Table 3-6).

Table 3-6 Teak provenance trials

Established year	No. of provenance	Location
1982	18	Pyinmana
1983	16	Oktwin
1986	12	Pyinmana
1998	10	Oktwin
2007	8	Pyinmana
2007	9	Kyaukdaga

Institutional Arrangements

Forest management in Myanmar developed over centuries. Myanmar kings formulated a complex system designed to maximize revenue and control. The teak trade was controlled by regulating extraction from the forest under a system of girdling, and Myanmar's involvement in the teak trade predated that of the Europeans. Systematic forest management was initiated in 1856, and, until recently, the guiding principles had been derived from a policy document prepared in 1894 (Gyi & Tint, 1998).

The forest policy recognized and emphasized the following six imperatives: (1) the **Protection** of soils, water, vegetation and wildlife, (2) **Sustainability** of forest resources to ensure perpetual supply of both tangible and intangible benefits accrued from the forests for the present and future generations, (3) the **Basis needs** of the people for fuel, shelter, food and recreation, (4) **Efficiency** to harness, in a socio-environmentally friendly manner, the full economic potential of forest resources, (5) **People's participation** in forest management and biodiversity conservation and utilization of forest resources, and (6) the **Awareness** of the vital role of the forests in the well-being and socio-economic development of the nation.

The Burma Forest Act 1902 and subsequent amendments were in use until the Government promulgated new forest legislation in November 1992. The important instruments for implementation of forest resource management and biodiversity conservation are:

1. Forest Policy (1995, revised in 2018);
2. Forest Law (1992, revised 2018);
3. Forest Rules (1995);
4. Protection of Wildlife and Wild Plants and Conservation of Natural Areas Law (1994);
5. Myanmar Agenda 21 together with Environmental Policy
6. Departmental Instructions for Forest Officers in Myanmar 1955
7. Working Plan Manual, Myanmar 1938
8. Standing Orders for Subordinates, Forest Department 1959
9. Community Forestry Instructions 1995 (revised in 2019)

The policy prescribes, inter alia, the following facts;

1) to gazette 30% of the total land area of the country as reserve forest and 5% under a protected area system;

2) to introduce a system of environment pricing based on the "polluter pays" principle to compensate for environmental and ecological degradation;

3) to pursue a sound programme of forest development through regeneration and rehabilitation operations to optimize productivity from natural forest;

4) to recognize that plantation forestry is not a substitute for natural forest management;

5) to promote efficient harvesting and sustainable utilization of all forms of forest produce; and

6) to enlist people's participation in forestry sector development activities in order to provide "people-based development" and also create public awareness and mass motivation for the protection and conservation of forests.

Moreover, the new Forest Law, in line with the Myanmar Forest Policy, focuses on a balanced approach towards conservation and development issues implicit in the concept of sustainable forestry. It describes the decentralization of the management system and opening up the opportunities to the private sector investment in the plantation establishment. In addition, it does highlight the environmental and biodiversity conservation, and encourages the community forestry and people's participation in forest management but prescribes more severe punishments for forest offenses.

Under the Ministry of Natural Resources and Environmental Conservation, the Forest Department has the primary responsibility for the administration and management of the forestry sector. The organizational structure comprises a combination of government agencies such as the Planning and Statistics Department, the Forest Department, Myanmar Timber Enterprise, the Dry zone Greening Department, the Environmental Conservation Department, the Survey Department, University of Forestry and Environmental Sciences, Department of Mines, Department of Geological Survey and Mineral Exploration, No. 1 Mining Enterprise, No. 2 Mining Enterprise, Myanmar Gems Enterprise, Myanmar Pearl Enterprise. Among these departments, the Forest Department (FD) is mainly responsible for the research and development of forest management and conservation of biodiversity. Under the organizational structure of FD, the Forest Research Institute (FRI) and Central Forestry Development Training Centre (CFDTC) have been conducting the research works on genetic conservation and tree breeding and improvement by use of *in vitro* and *in vivo* propagation techniques.

Conclusion

About half of the land area of Myanmar is still covered with forests, of which 38 % is composed of the mixed deciduous forest types where Teak grows naturally well as Teak bearing forest. The forestry sector has contributed significantly to the country's economy and timber, especially Teak wood, has been major source of export earnings for many years. More than a century and a half of scientific management the natural forests of Myanmar are still in comparatively good extent and condition. But much efforts are needed which focused on the management of natural forests to provide timber, and strengthen the protective functions to ensure environmental stability and ecosystem integrity. Moreover, the large-scale Teak plantations are now being established through the application of modernized techniques and the involvement of private enterprises, to complement the primary effort in the natural forest management.

The destruction of the natural teak forests is a global concern. The issue is not confined only to the countries where these forests exist. The developing nations with low financial development are simply incapable of just conserving and improving the forests, and they have to utilize the forest resources for their economic and social development. In this perspective, multidisciplinary, multisectoral and multinational approaches is essential to ensure the sustainable management of natural teak forests for continued supply of quality timber to satisfy the needs of both present and future generations.

References

Armstrong, K. (2004). A Checklist of the Trees, Shrubs, Herbs, and Climbers of Myanmar. In: W. John Kress, Robert A. De Filipps, Ellen Farr & Daw Yin Yin Kyi (eds.). Washington, DC: Smithsonian Institution. Contributions from the United States National Herbarium, Vol. 45. 2003. 590 p. ISSN 0097 1618. Available free of charge while supplies last. *Edinburgh Journal of Botany*, *61*(2-3), 197-198.

Dawkins, H.C. & Philip, M.S. (1998). *Tropical moist forest silviculture and management: a history of success and failure*, 359 p.

FAO. (1956). *Country Report on Teak*, Rome. Italy.

FD (Forest Department). (1997). Country report- Union of Myanmar. *Asia-Pacific forestry sector outlook study*, Working paper series. Working Paper, No: APFSOS/WP/08.

FD (Forest Department). (2000). Historical review of teak forestry in Myanmar In *A paper presented at the Third Regional Seminar on Teak* .31 July- 5 August, 2000, 13 p. Yogyakarta, Indonesia.

FRA (Global Forest Resource Assessment). (2020). *Food and Agriculture Organization of the United Nations. Myanmar Country Report*, Rome. Italy.

Gyi, M. K. K. & Myint, Z. W. (2008). *Timbe for conservation Myanmar Teak*. Seminar on Teak Seed Production Area Management and Tree Improvement, ITTO Project PD 270/04 Rev. 2(F). Naypyidaw, Myanmar.

Gyi, M. K.K. & Tint, K. (1998). *Management of Natural Teak Forest, Natural Teak Forest management Practiced Under the Myanmar Selection System*. In FAO, *Teak for the Future-Proceeding of the Second Regional Seminar on Teak*. Rome, Italy.

Hlaing, Z.C. (2012). *The growth of teak plantations (Tectona grandis* Linn.f*) in Bago Yoma Range, Myanmar*. MSc thesis, Seoul National University, South Korea.

Htun, K. & C. Hlaing. (2001). *A general assessment of teak plantations in the Bago Yoma region*, *Yangon, Myanmar*. FRI Leaflet No.8. Forest Science Research Paper, Forest Department.

Kermode, C.W.D. (1964). *Some aspects of silviculture in Burma*. Central Press, Rangoon.

Kyaw, N. N. (2003). *Site influence on growth and phenotype of teak (Tectona grandis* Linn. f*) in natural forests of Myanmar*. Ph.D. thesis, Cuvillier Verlag, Gottingen, Germany.

Kyaw, T. (2002). *The present state of growth, composition and structure of teak forests*. AvH research paper, 21 p. (unpublished).

Myint, S., Htun, K. & Hlaing, C. (1999). *Evaluation of Commercial plantations in Myanmar*, Study 2, Yangon, Myanmar: GCP/RAS/158/JAP.

Soe, K. K. (2009). *Growth performance of Teak (Tectona grandis* Linn.f*) plantations in moist and dry ecological zones in Myanmar*. MSc thesis, University of Technology, Dresden, Germany.

Chapter 4: Natural Teak Forests and Plantations in Lao PDR

Vongvilay Vongkhamsao, Baisone Inthirath and Bounthavy Chaleunsouk

Abstract

Lao PDR forms the easternmost limits of the natural distribution of Teak in the world. The largest natural areas in Laos occur in the Sayabouly Province, where there may be 10-20,000 ha of mixed deciduous forests with significant presence of teak. Small areas of teak are also found in the Bokeo Province. In order to conserve natural teak forest, Government of Laos has both policies and regulations in place and several projects are under implementation to manage teak and ensure its sustainable use. Teak has long been grown by small farmers in northern part of Laos, especially in Luang Prabang with an average parcel size of less than 1 ha. Larger areas, up to around 20 ha, are often owned by absentee owners or acquired overtime by entrepreneurs. For many of these plantation owners securing land use rights is the primary benefit. The planting of teak has been promoted by Government policies since the 1980s in recognition of its high value and its potential to provide opportunities for generation of farm income. The so-called '2+3 model' encouraged by the government, in which the smallholder provides land and labour while the plantation company is responsible for technology, finance and marketing, has been quite successful in attracting investment in teak planting.

Introduction

Lao PDR (or Laos) has a rich natural forest resource base which plays a significant role in the country's economic development with tree logging and export of timber to external markets in Vietnam, Thailand and China being an important source of income enhancing the diversification of national economy. The First National Forest Conference held in 1989 declared the rapid pace of forest degradation in the country had created a crisis situation which must be resolved through active rehabilitation of natural forests and establishing new forest plantations (Gilmour & Tsechalicha, 2000).

Acting on its recommendations the Government of Lao PDR has been strongly encouraging all relevant stakeholder such as state authorities, entrepreneurs and individual local villagers to protect the existing forests and grow more forests.

Teak is a large deciduous tree and a member of the family Verbenaceae. Teak is a very suitable species for farmers to plant because its growth is initially fast and it is fire resistant (Kaosa-ard, 1989). Teak is indigenous to central and south India, Burma, northern Thailand and in two small areas in northwestern Laos (Hansen et al., 1997). Teak has been planted in a small and moderate scale in other tropical countries such as Bangladesh, east and west Africa, Central and South America and on many islands of the Atlantic, Pacific and Indian Oceans (Kadambi, 1972).

Teak (*Tectona grandis)* is one of many native tree species that have been selected for planting across the country. According a national survey of forest plantation in Laos during September and December 1990 carried out by Forest inventory and Management Office, Department of Forestry there were 6,250 ha, about 3,000 ha was classified as stock planation, nearly 50% of planation area was teak *(Tectona grandis)* while eucalypt plantation was 6% of the total area (Mounda, 1995). Teak is very popular among local villagers, especially in Luang Prabang Province, due to its shorter harvesting rotation of 15 years and highly valued golden wood used to make furniture, housing material and etc. both for internal market and for export to external markets particularly China.

In Lao PDR, teak occurs naturally only in the provinces of Sayabouly and Bokeo bordering Thailand and Myanmar, but has been planted extensively in the provinces of Luang Prabang, Sayabouli, and Champasak (Nahuel et al., 2019). Luang Prabang is one of many provinces where teak tree is popularly planted by local people in large numbers. It began very small with just 3 ha in 1975 growing to 7,837 ha in 1999 (Kolmert, 2001) and by 2012 the extent of land covered by teak plantations had risen to 26,500 ha (Midgley et al., 2015). Most of these teak plantations were in annual crop farmlands located along both road side, rivers and mountain valleys, from flat lands to steep slopes, from lower elevations to higher reaches in the mountains.

Natural Teak Forests

Lao PDR forms the easternmost limits of the natural habitat of teak where it occurs naturally in the northwestern provinces of Xayyabouly and Bokeo along the Lao-Thai border (Kaosa-ard, 1989). Till a few decades back these natural forests with significant presence of teak used to extend over more than 30,000 ha but are limited to about 16,000 ha now (Midgley et al., 2015). The largest natural areas occur in the Sayabouly Province, where there may be 10-20,000 ha of mixed deciduous forest with inclusion of teak with smaller extents spread over the Bokeo Province (Antilla, 2016).. Natural teak forests play an important role in ecological system and environmental protection and form an important source for supply of seed for plantations. In 2000-2003, the Lao Tree Seed project established 102 tree seed sources across the country of which 76 seed sources remain operational till date (Figure 4-1). Among these currently operational seed sources, nine serve the demand for teak seeds in the country one of which is located in natural teak forests (Khamphoumi et al., 2017) and one is supported under the ITTO Teak Project in Mekong.

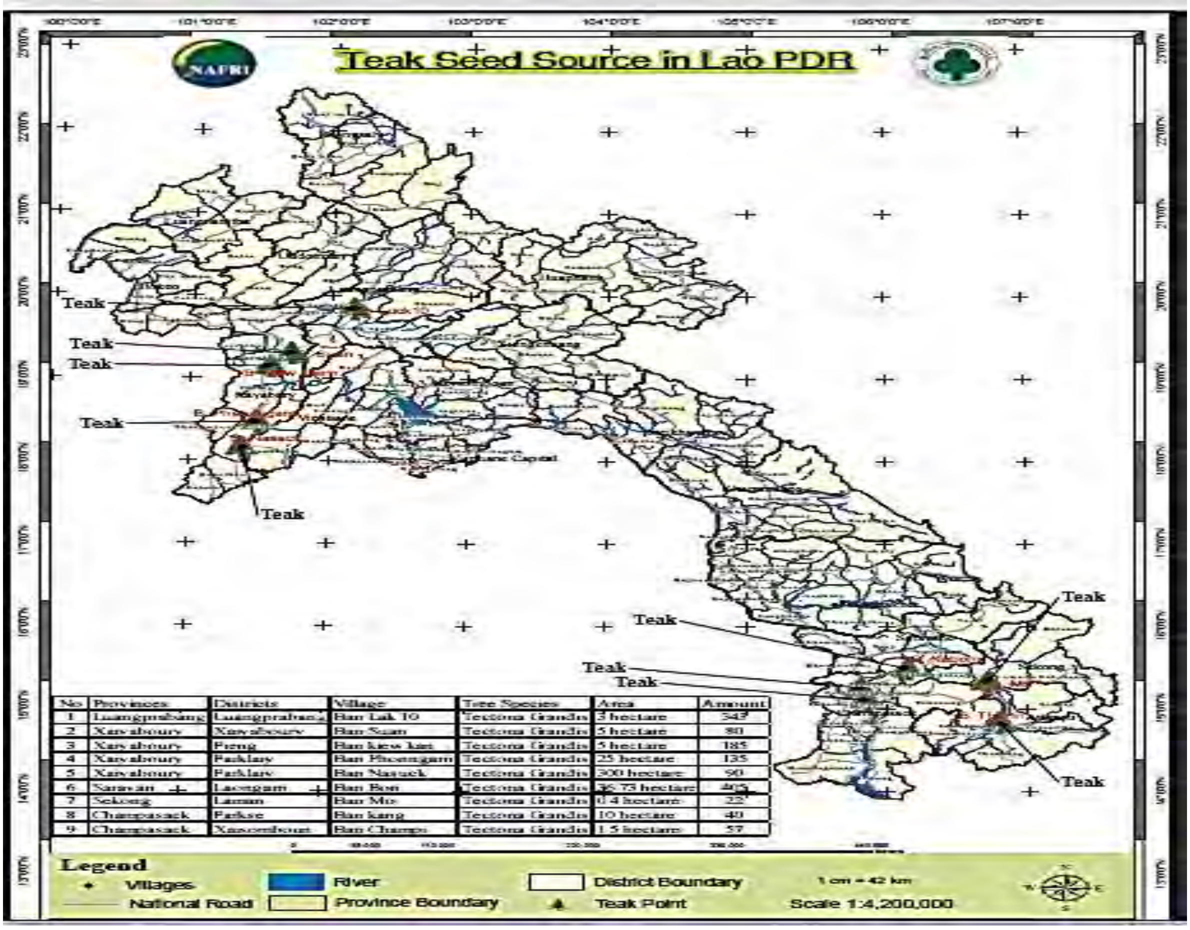


Figure 4-1 Map of teak tree seed sources in Lao PDR

Teak Plantations in Lao PDR

With the sharp drop in area under teak in natural forests it is recognized today as a 'special tree' and attracts specific protection under the national legislation. The planting of teak by smallholders has also been promoted by government policies since the 1980s in recognition of its high value its potential to provide opportunities for generation of farm income, and to increase lands under permanent production of highly valued teak

instead of temporary cultivation of paddy under shifting cultivation on steep hill slopes. Demonstration of teak propagation and plantation began in 1915 on small scale in Luang Prabang province and then was taken up at commercial scale beginning 1942 (Midgley et al., 2015). The civil war brought the progress to a halt between 1975 to 1996 after which the Laotian government has been promoting teak planting across the country bringing the area under teak plantation from a mere 2,937 ha in 1990 to 40,000 ha in 2012 (DoF, 2013).

In northern Lao PDR, the expansion of smallholder teak plantations in the past decade has contributed to a transition from swidden farming landscape to a forested landscape, in line with the government policy objectives to eliminate swidden agriculture and increase the nation's forest cover. Driven by a range of incentives, teak plantations have become increasingly prominent in the province of Luang Prabang, especially in villages close to Luang Prabang City. Both smallholders and urban-based landowners are now involved in small-scale teak plantations, either by planting land they previously used for swidden agriculture or by acquiring existing teak stands (Newby et al., 2014).

Luang Prabang provincial authorities had considerable success in their efforts to promote teak plantations with the hope of getting good amount of valuable teak timber at the harvesting rotation of 15 to 25 years. But the teak output in quality and quantity was not as per the expectations as due care of the seed source and the soil quality of the planting sites was not taken. Planting was often undertaken on lands between elevation of 700 to 1000 meters and seeds were collected from unknown mother trees (Hansen et al., 1997). Moreover, most plantations had high stocking of 1600 – 1700 trees per ha without a prescribed regime for thinning that led to the production of a large proportion of low-quality trees and poor returns (Dieters et al., 2014).

Teak woodlots and agroforestry systems represent approximately 11% of the planted forest area in Lao PDR, and 42% of the plantation timber resource; there are over 15,300 hectares of teak in Luang Prabang Province alone. Farmers own a large proportion of planted teak. The average plantation parcel size is small, at around 0.75 hectares (Smith. et al.,2017).

Luang Prabang is one of many provinces where teak tree is popularly planted by local people over shared plantation area of community owned lands, a practice that began at very small scale in 1975 and rose to 7,837 ha in 1999 (Kolmert, 2001) and then up to 26,500 ha in 2012 (Midgley et al., 2015). Most of these plantations have been raised under the Taungya system with teak intercropping with annual crops such as upland rice, maize and sesame in the first three years followed by annual weeding once a year until 7^{th} year. The spacing advised is 2 x 2 m and 3 x 3 m in order to promote teak stem growth in height more than the diameter. Most of these plantations are on lands that were used to grow annual agriculture crops located along road sides, and along rivers and mountain valleys, on flat lands to steep slopes, from lower to higher elevations. There has been a concerted program of plantation development in Lao PDR since 1975 (Figure 4-2) and rates of establishment have generally increased in the past 40 years. By 2015 there were an estimated of 446,000 ha of plantations in the country (DoF, 2015).

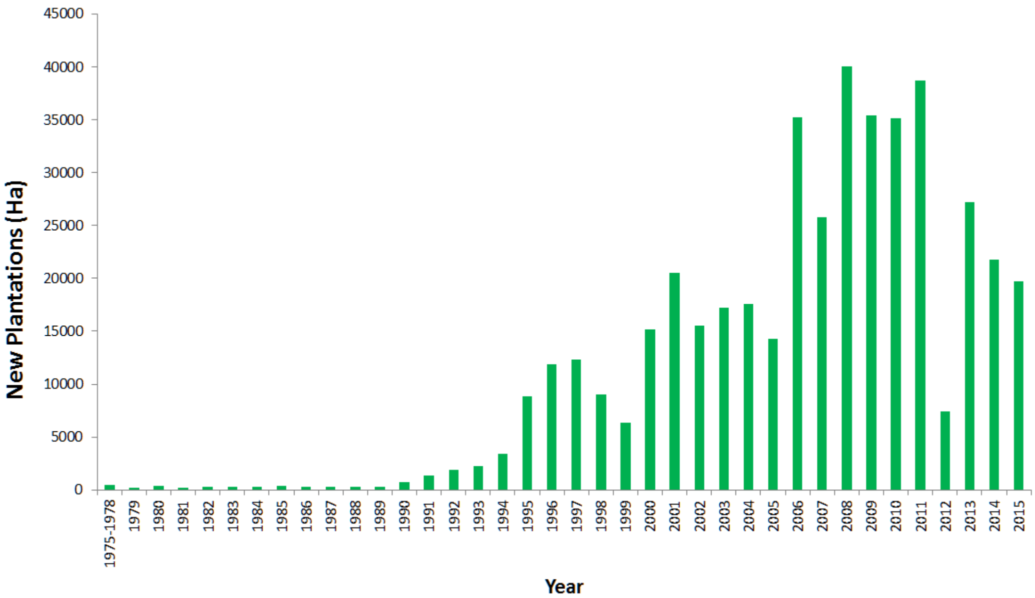


Figure 4-2 Annual plantation establishment in Lao PDR 1975-2015

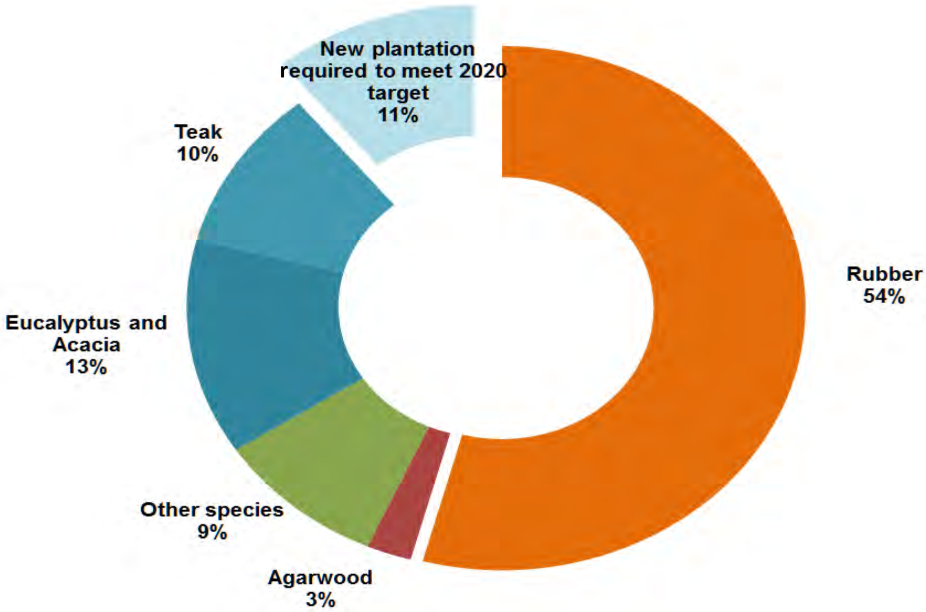


Figure 4-3 Comparison of planted tree species

Of the current plantation area, over 50% is rubber plantation with smaller areas of teak, eucalyptus and acacia, agarwood, and other, mostly indigenous species (Figure 4-3). Tree plantations are being established in a variety of planting patterns and silvicultural arrangements including monospecific plantations with one single tree species, mixed plantations with two or more tree species, tree intercropping with coffee etc, and scattered and boundary tree planting on agriculture lands. Besides, complex agroforestry with multiple wood producing and non-wood producing trees/plants established over an area resulting in a multi-layered structure is also sometimes practiced.

The main known sources of plantation grown wood are smallholder teak plantations (*Tectona grandis*; 'mai sak') and Eucalyptus and Acacia from largely investor owned/managed plantations. Other species grown in plantations such Agarwood (*Aquilaria crassna*; 'mai ketsana'), Benzoin (*Styrax tonkinensis*, 'mai nyarn') and Yang (*Nothalphoebe umbellifiora*, 'mai bong') are not typically grown for timber products, but rather are harvested for aromatic wood, resin or bark for processing into incense or oil. Pink Mampat (*Cratoxylum formosum* and *Cratexylon prunitfolium*, 'mai tiew') is grown typically under a coppice system for white charcoal. Other native species that have been planted include *Pterocarpus macrocarpus*, *Afzelia xylocarpa* and *Alstonia scholaris* although their exact areas and production volumes are not known.

Several of these species are promoted for planting during National Arbor Day but precise records of actual planting and survival are not kept.

Rubber is established principally for latex, and there is currently no formal value chain for rubber wood in Lao PDR, although anecdotally rubber wood logs are being exported to China from northern Lao PDR, where plantations are being harvested due to low latex prices. Around 54,000 ha of new plantations are needed to be established between 2016 and 2020 to reach the 500,000-ha target.

In addition, the government has introduced different types of ownership patterns to encourage foreign companies to invest on tree plantations, the most common of which is "2 + 3 model". In this model the farmer contributes land and labor (2) while the company/investor is responsible for technology, finance and markets (3) as described below:

Table 4-1 Types of Plantation Ownership

Ownership models	Land	Labour	Capital	Market	Technology
Smallholder (5+0) with own capital	●	●	●	●	●
Smallholder (5+0) with government officials	●	●	●	●	◆●
Contract Farming 4+1 smallholders (credit)	●	●	●	◆●	◆
Contract Farming 3+2	●	●	◆●	◆	◆
Contract Farming 2+3	●	●	◆	◆	◆●
Contract Farming 1+4	●	◆●	●	●	◆●
Concession Farming	◆	◆	◆	◆	◆

Note: ● = farmer inputs; ◆company inputs

Source: Phimmavong et al. (2009)

Smallholder plantations are also diverse. The majority of teak plantations are owned by individual famers, with an average parcel size of less than 1 ha (Smith ,2016). It is estimated that there are possibly over 15,000 plantation owners in Luang Prabang.

Larger areas, up to around 20 ha in size may be owned by absentee owners, who may be either farmers who have recently moved into more urban centres or which have been acquired overtime by entrepreneurs. For many of these plantation owners securing land use rights is a primary benefit.

Demand for Teak Wood

Teak wood is consumed locally, as well as processed domestically and exported. The volume of wood that is consumed locally, by households and within villages, is not known. The bulk of log and wood exports from Lao PDR are either unprocessed logs or basic sawn wood and planks, with minor quantities further processed into components, strip parquet flooring, furniture and various other secondary products. Midgley et al. (2011) found that Lao exports of timber derived from plantations were dominated by teak, a large proportion of which was in the form of squared logs. The main markets are China, Thailand and Vietnam, and India is emerging as a purchaser of Lao teak (Midgley et al., 2015). Keonakhone (2005) estimated that about 95 % of the teak wood produced in Luang Prabang was exported and only 5% is used locally, which includes teak residues produced in preparation of squared logs. Teak thinning is sold as poles although this is not a formally recognised wood product in regulations. Teak is used by domestic wood processors and furniture makers, although volumes are low (ACIAR FST/2010/012 unpublished data) and there is still a dependence on and preference for wood from natural forests. Estimated domestic demand for teak in Lao PDR is about 30,000 m3 per year (Soulignamath, 2020).

The annual harvesting of planted trees is increasing but remains limited because demand from consumers in developed countries is constrained by the requirements of certification. The perceived strong demand for certified products in the US and Europe coupled with maturing teak resources in northern provinces resulted in a program for Forest Stewardship Council or FSC group certification of smallholder teak plantation

The absence of mapping, inventory, and appropriate growth and yield models for teak and other naturally occurring species has meant that predicting volumes and

called the Luang Prabang Teak Program (LPTP). This program suspended its FSC certification in 2016 but continues to operate to provide support to teak smallholders.

Wood Supply

Precise statistics on wood production in Lao PDR are difficult to obtain, and there are discrepancies in production, consumption and export data. There are no consolidated statistics on wood production from Eucalyptus or Acacia plantations. Data on yields and harvesting are held by individual companies.

Commercial tree planting is on the rise, with a total investment of more than 1.5 billion USD, of which foreign investment is 1.4 billion USD. In addition, investment in tree plantation in degraded forestland and barren forestland in government-allocated production forest areas or in the land of individuals, legal entities or organizations with land allocated by government is being promoted. Regulations on the management and use of plantations including logging, transportation, trade and export of plantation wood have been improved in a coherent way.

With respect to teak harvesting, the available statistics are not always reliable because of internal inconsistencies. In 2006 it was estimated that over 7000 m^3 of plantation-grown teak were harvested in Luang Prabang Province and 20,000 m^3 in 2010 (Savathvong, 2010). Midgley et al., (2015), however, noted that substantially higher volumes are reported by importing countries than those recorded in official Lao trade statistics. In 2012, for example, combined teak imports into China, Thailand and Vietnam from Laos were reported as 10,670 m^3 while exports from Lao were recorded as 3,655 m^3. Similar variations were also found for 2013.

long-term supply has been difficult. Research being undertaken by two other ACIAR projects is addressing this issue. For example, in Luang Prabang Province over 15,000 ha of teak plantation has been mapped and classified down to 0.35 ha parcels. Combined with field-based inventory and the application of growth and yield models, to be undertaken during the next phase of that project, a better picture of the nature of that resource will be developed (Boer & Seneanachack, 2016). In addition, the Luang Prabang Teak Program that began in 2008 has attempted to empower local farmer in charge of improvement of silvicultural practice, plantation fluctuations, certification by Forest Stewardship Council and wood processing and trading. Till 2014 teak plantations over 220 ha had been registered and received certification by FSC, but most local villagers have been selling standing trees to local traders getting low price due to lack of quality classification even though provincial forestry offices have issued guidelines for grading round logs. Local wood processing entrepreneurs have their own quality grades that includes wood color because of premium on golden color in export markets though domestic teak market does not have this requirement yet.

Challenges, Opportunities and Recommendation

Challenges

There have been several serious efforts on the part of the Laotian government in support of sustainable management of the natural and planted teak resources of the country reflected in a number of poicies and strategies developed over the years but there are many weak areas that need special care. Some of these challenges are listed below:

- Land encroachment in natural teak forests for agriculture, roads, buildings and other infrastructure is a serious challenge for future management.
- Difficulty in protection of Mother trees identified for seed production
- Lack of markets for seeds, no seed networks
- Forest fires
- Lack of regular monitoring and maintenances of teak plantations raised over the years. The boundaries of the plantations are often indistinguishable. Weedings are not carried out in time.
- There is till lack of awareness about the importnce of timber certifcation and plantation regsitaration among farmers as a result of which they do not get market prices for their timber and timber products.
- Demand for processed wood from the plantations is limited to the small domestic market. Export is mostly in round logs.
- Consumer's access to market information related to wood quality, specifications, designs, standards, requirement of certification in consumer country, flucuations in price, etc is limited.
- Changes in regulations, such as ban on export of round longs, also restrict market access to the teak planters.
- Policies for plantation and rehabilitation of forest have not been implemented and elaborated in accordance with the law.

Opportunities

1. The Government has brought out a number of poicies and strategies to support sustainable forest management, such as Forest-2035 andVision 2050, aiming to increase forest cover to 70% of tatal land area of the country and managing it sustainably.
2. Commercial tree planting is on the rise, with a total investment of more than 1.5 billion USD, of which foreign investment is 1.4 billion USD. In addition, investment in tree plantation in degraded forestland and barren forestland, and on government-allocated production forest areas to individuals, legal entities or organizations is being

promoted. Regulations on the management and use of plantations including logging, transportation, trade and export of plantation wood have been improved in a coherent way (FS2035).

3. There is high and increasing demand for teak wood from both local and international markets.
4. Application of science, technology and innovative research results in management, monitoring and inspection of forests and forestlands is growing and being developed.
5. Cooperation and technical supports and funding from domestic and international development partners have been received, as well as investment in forestry from individuals, legal entities and domestic and foreign organizations are on the rise.

Recommendations

Based on this review a number of preliminary recommendations can be made as a basis for further analysis and development for conservation of natural teak forests and for the promotion of teak plantations as follows:

1. Clearly define boundaries of teak conservation areas and continue to protect and maintain them raising awareness for the need for it among the citizens,
2. Establish tree seed sources and promote utilization of seeds from established seed sources, set up tree seed networks for sharing information, improve tree seed quality, and enhance accessibility to high quality seeds to the remotest farmer
3. Disseminate rules and regulations for teak conservation areas and seed sources
4. Provide training to local authorities and farmers on seed collections, seed handling and storage.
5. Strengthen public-private collaboratives action
6. Improve the availability of high-quality teak germplasm for use in new plantations and agroforestry systems, test teak provenances, and establish orchards to produce better quality seed.
7. Conduct research and development of techniques for tree improvement, seed procurement and nursery production;
8. Promote better establishment and management practices that will improve returns to farmers and industry including training on silvculture techniques, pruning, thinning, harvesting and volume calculation of wood for selling.
9. Simplify regulations to make it easier for farmers to legally register, harvest and sell their teak trees to improve the efficiency of the value chain
10. Clearly separate tree plantation policy and regulations from those governing management, harvest and use of wood from natural forests
11. Promote local processing enterprises, since these are more likely to increase financial returns to teak farmers.
12. Consider potential financial mechanisms (such as levies on plantation area or timber production and processing) to support cooperative research between the processing industry and teak planter.

Conclusions

Lao PDR is one of the few countries in world that have a rich natural forest resource which is playing a significant role in the development of the country over the past several decades. Natural teak forest plays an important role in ecological system and environmental protection and provides high quality seeds for planting teak. Currently there are nine teak seed sources, one from natural teak forest and one of them has been supported by ITTO Teak Project in Mekong. In order to promote sustainable use of natural teak forest, it is important to get local people to get benefits and involvement in various activities such as seed collection for sale, building capacity for them and raising awareness of the role of natural teak forest for their livelihood.

Teak has long been grown by farmers in northern part of Laos, especially in Luang Prabang Province. The planting of teak has been promoted by Government by policies enacted since the 1980s in recognition of its high value, its potential to provide opportunities for generation of farm income and to promote permanent production.

Teak woodlots and agroforestry systems represent approximately 11% of the planted forest area in Lao PDR, and 42% of the plantation timber resource; there are over 15,300 hectares of teak in Luang Prabang Province alone, 39% of mapped teak is small in size (less than 15 cm diameter at breast height); only 4% is bigger than 25 cm or commercial size. Farmers own a large proportion of planted teak. The average plantation parcel size is small, at around 0.75 hectare

Research and development for improving good materials for future teak plantation is very importance. Government policies for teak forest conservation and promoting plantation are very crucial, especially land use planning, plantation management, harvesting, processing, trading.

References

Antilla, J. P. (2016) *Implications of middlemen in smallholder teak production systems in Northern Lao People's Democratic Republic (Lao PDR),* Unpublished Master's Thesis. Faculty of Agriculture and Forestry, Department of Forest Sciences, University of Helsinki.

Boer, K. & Seneanachack, H. (2016) *Mapping and Characterisation of Plantation Teak in Luang Prabang Province, Lao PDR.* Objective 1: Final Report. Completed as a component of the Australian Centre for International Agricultural Research (ACIAR) funded Project FST/2010/012 Enhancing Key Elements of the Value Chains for Plantation Grown Wood in Lao PDR, 22 p.

Dieters, M., Newby , J., Cramb. R. & Sexton, G. (2014). *Enhancing on-Farm Income through Improved Sericulture Management of Teak in Luang Prabang Province of Lao. PDR*. Australian Centre for International Agricultural Research, Canberra, Australia.

Department of Forestry (DoF). (2013). Annual report on achievements of forestry implementation. Vientiane, Lao PDR.

Department of Forestry (DoF). 2015. Unpublished plantation statistics. Vientiane, Lao PDR

Gilmour, D. & Tsechalicha, X. (2000). Forest Rehabilitation in Lao PDR: Issues and Constraints. IUCN Laos, Vientiane, Lao PDR, 96 p.

Hansen, P.K., Sodarak, H. & Savathvong, S. (1997). Teak Production by Shifting Cultivators in Northern Lao PDR. Lao Swedish Forestry Program, Luang Prabang, Laos.

Kaosa-ard, A. (1989). Teak (*Tectona grandis* L.f.) its natural distribution and related factors. *Natural History Bulletin of the Siam Society, 29*, 55-74

Kadambi, K. (1972). Silviculture and Management of Teak. *Forestry Bulletins*

No.24.https://scholarworks.sfasu.edu/forestrybulletins/23 (accessed 30 December 2021).

Khamphoumi, B., Thammavong, B., Vongkhamhor, S., Xayavong, S. & Vongkhamsao, V. (2017). Tree seed source management and utilization assessment in the Lao PDR. *Lao Journal of Agriculture and Forestry*, 37, 132-148.

Keonakhone, T. (2005). *A holistic assessment of the use of teak at a landscape level in Luang Prabang, Lao PDR*. Unpublished Master thesis, Departments of Forest Soils and Soil Sciences, Swedish University of Agricultural Science. Uppsala, Sweden.

Kolmert, A. (2001). *Teak in Northern Laos*. Swedish University of Agricultural Sciences: Uppsala, Sweden.

Midgley, S., Bennett, J., Samonty, X., Stevens, P., Mounlami, K., Midgley, D. & Brown, A. (2011). *Scoping Study Payments for Environmental Services and Planted Log Value Chains in Lao PDR*. ACIAR projects FST/2011/003 and FST/2010/012.

Midgley , S., Mounlamai, K., Flanagan, A., Phengsopha, K. (2015). *Global markets for plantation teak; Implication for Grower in Lao PDR*. Australian Centre for International Agricultural Research: Canberra, Australia.

Mounda, B. (1995). *Eucalyptus in Lao PDR*. https://www.fao.org/3/AC772E/ac772e0a.htm#TopOfPage (accessed 2 January 2022)

Nahuel, A., Pachasa. A., Sakanphet . S., Soukkhy, S., Soukkhy, O., Lao, M., Savathvong, S., Newby, J.C., Souliyasack, B., Keoboualapha, B. & Dieters, M.J. (2019). Initial spacing of teak (Tectona grandis) in northern Lao PDR: Impacts on the growth of teak and companion crops. *Forest Ecology and Management*, 435, 77-88.

Newby, J.C., Cramb, R.A. & Sakanphet, S. (2014) Forest Transitions and Rural Livelihoods: Multiple Pathways of Smallholder Teak Expansion in Northern Laos. *Land*, 3, 482–503.

Phimmavong, S,, Ozarska, B,, Midgley, S, & Keenan R. (2009). *Forest and plantation development in Laos: History, development and impact for rural communities*. International Forestry Review

Savathvong, S. (2010). *Report on the Process of Imposition of Taxes on Planted Teak Transactions – A Case Study in Luang Prabang Province.* Souphanouvong University, Faculty of Agriculture and Forest Resources, Lao PDR.

Smith, H. (2016). *Making Smallholder Plantation Owned Wood legal: Alternatives to Plantation Registration*. Final Report for Objective 1.2a Completed as a component of the Australian Centre for International Agricultural Research (ACIAR) funded Project FST/2010/012 Enhancing Key Elements of the Value Chains for Plantation Grown Wood in Lao PDR, 45 p.

Smith, H F., Dieters, M., Newby, J., Kanowski, P., Keenan, R. & Bartlett. T. (2017). *Smallholder Teak Woodlots and Agroforestry Systems in Lao PDR.* ACIAR Policy Brief Research Findings with policy

Chapter 5: Teak Plantations in Cambodia

Say Sinly, Chheang Dany, Kim Sobon,
Lim Sopheap, Hort Sothea and Pang Phanit

Abstract

The Cambodia ITTO Project Team expresses its appreciation to everyone involved in reviewing the National Report on Teak Plantation in Cambodia.

The production of this report was funded by the International Tropical Timber Organization (ITTO) through the ITTO Project "Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region" is gratefully acknowledged.

This chapter would not have been made possible without the support and encouragement of the Forestry Administration in Phnom Penh, especially H.E. Dr. Keo Omaliss, Delegate of the Royal Government of Cambodia, Director General of Forestry Administration, as well as other Senior Officials of the Forestry Administration.

It is important to recognize the assistance and cooperation of Mr. Keo Kosal and Grandis Timber Co., Ltd, especially Mr. Cheat Vichit, who assisted the project team in establishing demonstration plots and collecting measurement data quarterly during the course of this project. Also, it is to concede the inputs from Mr. Chhun Virak, the owner of Teak Wood Furniture Cambodia, who shared information and photos of teak products from his own teak wood manufacturing craft.

We acknowledge as well, the active participation of Provincial Forestry Administration Cantonments for kindly providing input data related to teak farm plantations in respective provinces including Kampong Cham Forestry Administration Cantonment; Tboung Khmum Forestry Administration Cantonment; Ratanakiri Forestry Administration Cantonment; Kampong Spue Forestry Administration Cantonment; Kratie Forestry Administration Cantonment; Kampot Forestry Administration Cantonment.

The collective efforts of Cambodia Project Team in preparing the report includes Dr. Chheang Dany, Dr. Dennis J. Cengel, Mr. Say Sinly, Mr. Hort Sothea, Ms. Lim Sopheap, Mr. Kim Sobon, Mr. Pang Phanit, Mr. Neab Keng, Mr. Vann Vean, Mr. Phoung Sophea, Mr. Kong Kongkea, Mr. Buor Vuthy, Mr. Sin Chandara, Mr. As Brosden, Mr. Nuon Sithun, and Ms. Ouch Sineth are acknowledged.

Finally, we would like to express our appreciation to all of the other specialists who took their time to review this report.

Introduction

Global Distribution and Production of Teak

Teak plantations disperse in over 70 countries. The natural teak forest was found only in India, Laos, Myanmar and Thailand, later it was discovered that teak was introduced in Indonesia between 400 and 600 years ago and get naturalised. Teak has become a major source of income for the forest economy, especially by private sector investment in countries in Asia, Africa, Latin America and other countries (FAO, 2015; Pandey & Brown, 2000; Verhaegen et al., 2010).

Global estimates put the natural teak forest at 29.04 million ha, almost half of which is in Myanmar, and 4.35 to 6.89 million ha of cultivated teak plantations, of which Myanmar is 0.39 million ha (Third in the world) (Kollert & Cherubini, 2012).

The size of the teak plantation had increased from the 1990s to just 2.25 million ha, since reduction in export of teak from the natural forest, especially the ban on teak business in Myanmar, India, Laos and Thailand. Since 1980s, teak plantations have been expanded in countries in Africa (0.47 million ha), tropical America (0.27 million ha), and Latin America could become a major source of planted teak (Pandey & Brown, 2000; FAO, 2009; Kollert & Cherubini, 2012).

According to the FAO, the demand and trade of tropical industrial timber worldwide is about 15 million cubic meters per year in 10 years (2005-2014), and the teak roundwood contributes more than 1 million cubic meters per year, equivalent to 7%, while teak sawnwood averaged 0.12 million cubic meters per year during the same period. The countries that export and supply teakwood include Myanmar (43% of teak roundwood and 50% of teak sawnwood) and countries in Latin America (Ecuador, Costa Rica, Panama and Colombia) and Africa (Ghana, Côte d'Ivoire, Benin, Togo and Nigeria). Major importers include India, Thailand, China, Taiwan, South Korea, USA, Europe and other Asian countries. The price of teak wood in the international market is between 350-1,000 USD per cubic meter (FAO, 2015; ITTO, 2020).

History of Teak Plantation Development in Cambodia

Teak was introduced to Cambodia in 1936 in Han Chey commune, Kampong Cham province, as an agroforestry system (Allouard, 1947). Many decades later, the expansion of teak has been made to other provinces such as Pursat and Ratanakiri Province (Narong et al., 2014).

Before 1963, Cambodia had been under French colony during which political control and territory administration were fully supervised by French. In 1930s, French commenced to carry out agroforestry system trials in Indochina for the enrichment of natural forests by intercropping method, which was applied throughout Southeast Asia-birth of agroforestry practices in Indochina (Allouard, 1947).

Enlargement of reforestation modes by inter-cultivation of agricultural crops (The practices by French):

In dense forest vegetation, all trees were cut down, and removed off what could be useful (lumber, firewood or charcoal., etc.), burned down whatever remain in place.

In this soil fertilized by ashes, trees were sown or planted. The local inhabitants were allowed to come for two years to cultivate agricultural crops on this land. Annually, the provided trees were maintained on such fertilized soil, often they obtained magnificent harvests; but after two years it was necessary to leave the place because the beneficial effects of burning would be gone. The trees grew to various sizes of brushwood which was not too troublesome, because during the first two years, the trees overcame the growth of these brushwood. The locals just had to wait until the trees had reached their diameter one another.

This method applied in many countries in South-East Asia had started to be experienced in Indochina (Cambodia) since 1936.

Photo 5-1 Teak plantation with cotton and corn in Han Chey commune, Kampong Cham province, 1936 (Source: archives forestières du Cambodge)

At the start of the first crop of the second rainy season, 1-year old teak trees were planted, and in the second crop of the second rainy season, Angkanh (*Cassia siameca* Lamk.), a fast-growing fuelwood species was grown to create afforestation.

It has been called the elimination of reforestation methods by intercropping or birth of agroforestry in Indochina. Such kind of reforestation-enrichment operations taken into consideration: (1) all quantities of wood harvested would lead to more or less uninhabited areas; (2) it would result in labor problems with the obligation to set up new villages, and create stable semi-agricultural areas, in addition to shifting cultivation previously used. The objective in these areas was to plant not only forest trees with annual agricultural crops but complemented by fruit trees of medium height and useful shrubs to create a set of plants (of agricultural interest or analog) in the form of the four stages of tropical vegetation of the dense forest type. This is what the local populations in Java had been practicing for a long time and that was agroforestry principle they were trying to develop in all tropical countries.

The future large trees were for timber production, while in the middle of these large trees, other smaller ones could be fruit trees, rubber trees, etc.; in red: shrub-like plants were plants to provide fruit (banana, papaya…etc.), or to produce for other various uses (coffee, fodder for livestock, etc.); in flat green: plants living at ground level could be tubers, pineapples, cane sugar etc.

The principle is as follows: the forest was felled and cleared in the dry season, then what had been felled was burnt, and trees were planted through seedlings or seeds between annual agricultural crops. In general, it costs almost nothing to the forest service, because the local people were always volunteers to do the job for free, including maintenance for 2 years. Indeed, this work was largely compensated by the miraculous crops due to the fertilizing effect of the ashes, which also benefit trees. After two years, it was given up, and there was hardly any maintenance until thinning.

The downside is the momentary depletion of the soil due to blowing. It may seem unexpected to see foresters advocating this apparently anti-ecological method, while they denounced cultivation on the burnt as the main culprit in the desertification of tropical forests. Repeatedly, here, there was really no problem, the damage was quickly recovered because of an increasingly intense forest cover and above all, because cultivation on the burnt was not practiced once, therefore, it was not regenerated.

The place chosen to set up this test was part of the Hanchey Reserve, close to Mekong River, not far from Kompong Cham province center. The place is near to the Pagoda, whose educational support to the locals was very useful, as always. The species of trees planted were teak (one of the best tropical woods) and Angkanh (*Cassia siameca*), a fast-growing tree used as fuelwood.

The area was cleared, and everything was burned in March, before the arrival of rainy season. The green trunks abandoned on the ground were logs without having any value which resisted fire.

A young teak in the foreground with corn crop recognizable by its large leaves of 4 months, seemed not yet to be well because the corn gave it shade (Photo. 5-1). Bean cultivation in the middle, a young 4-month teak taller than the other. The planned afforestation would be made of teak mixed with Angkanh trees (*Cassia siameca*.) which were already 2 meters high, with leaves not resembling to those of acacia species (Photo 5-1).

Within two years of intercropping agriculture (two crops per rainy season), afforestation was attempted. The expansion of teak planting through the above practices was no longer carried out from 1960 to 1980s due to continuous civil war in Cambodia.

Current Situation of Teak Plantation in Cambodia

Distribution of teak plantations Cambodia

Since 1990s, the afforestation in Cambodia was resumed, and the vast majority of tree plantations were conducted by the public institutions. In 1993, teak plantations were established at Teuk Chhar with more than 60 ha of land, and at Tboung Khmum at about 300 ha, and subsequently planted along the national road in Chlong district of Kratie province and near Ratanakiri province in the following years. Nevertheless, there was no available statistics.

Photo 5-2 Study visits to private teak plantation in Han Chey commune, Kampong Cham province and teak nursery at Grandis Timber Limited in Aoral district, Kampong Spure Province

In Cambodia, teak plantations currently exist between 6,200 and 7,000 ha equivalent to 7.2-10 million scattered trees in some provinces. The number of major teak plantations reported is 6,100 ha recorded in 6 provinces including Tbong Khmum, Kampong Cham, Kratie, Ratanakiri, Kampong Spure, and Kampot (Table 5-1 & Figure 5-1). However, the some other private teak plantations have not been reported, including teak trees that have been planted on public areas, especially at pagodas' compound and local public institutions' areas. These teak trees have been planted by local people as such agroforestry forms as living fence and intercrop, which are observed scattering in some other provinces such as Stueng Treng, Mondulkiri, Pursat, Battambang, and Prey Veng.

The rapid increase in teak plantations over the last two decades is on account of an investment by private sector and the government campaign via distribution of teak seedlings by local forest administrations to local communities for planting as tree plantations, agroforestry plantations (living fences and public areas).

Table 5-1 Teak Plantation in Cambodia

No	Name	Area[1] (ha)	Administrative Location	Type of Land Ownership	Date of planting started
1	Grandis Timber Limited	4848	Aoral and Phnom Srouch district, Kampong Speu province	Economic land concession	2014
2	Teak Farm	350	Aoral district, Kampong Speu province	Private company	2018
3	US Teak Plantation	300	Tboung Khmum district, Tboung Khmum province	Private company	2000
4	Chamkar Maisak Kampot	128	Dang Tung district, Kampot province	Private company	NA

[1]The data of teak plantation were obtained from respective provincial Forestry Administration cantonments and owners of private teak plantations, while the shape file of those teak plantations (on the map) were received through geo- referencing and tracking at the fields.

No	Name	Area[1] (ha)	Administrative Location	Type of Land Ownership	Date of planting started
5	Green Island	100	Sambor district, Kratie province	Economic land concession	NA
6	Teak Wood Furniture Cambodia	90	Lamphat district, Ratanakiri province	Private natural person	2001
7	Han Chey Teak plantation	87	Kampong Siem district, Kampong Cham province	Private natural person	2008
8	Tboung Khmum state teak plantation*	88	Tboung Khmum district, Tboung Khmum province	State tree plantation	1993
9	Teuk Chhar Teak Plantation	55	Prey Chhor district, Kampong Cham province	State tree plantation	1993
10	Stueng Trang Teak Plantation	11	StuengTrang district, Kampong Cham province	Private natural person	NA
11	Other	50	Kampong Siem district, Kampong Cham province	Public land (pagoda)	NA
	Total	**6,100**			

Note: * Tboung Khmum state teak plantation was first started with planting teak trees in 1993, and the total area was 300 ha. Since the government handed over this area to Tboung Khmum province for setting up provincial town and built-up area, there are about 88 ha of teak plantation remained.

Kampong Speu province is the predominant teak plantation in Cambodia. Grandis Timber Co., Ltd is an economic land concession (ELC) and Teak Farm (a private Israel company) have planted about 4,848 ha and 350 ha of teak trees since 2014 and 2018, respectively.

In Tbong Khmum province, there are 388 ha of teak plantation including 300 ha of US Teak Plantation (planted since 2000) and 88 ha of State teak plantation (planted since 1993). In Kampong Cham province, there are 163 ha of teak plantation consisting of 97 ha of private teak plantation (planted since 2008), 55 ha of Teuk Chhar State Teak Plantation (planted since 1993), and 11 ha of Teak on Hanchey pagoda.

In Kampot province, there are 128 ha of teak plantation, while there are about 100 ha of teak plantation that belongs to Green Island Company (ELC) in Kratie province. Last, in Ratanakiri there are 90 ha of private teak plantation belonging to Mr. ChhunVirak, the owner of Teak Wood Furniture Cambodia.

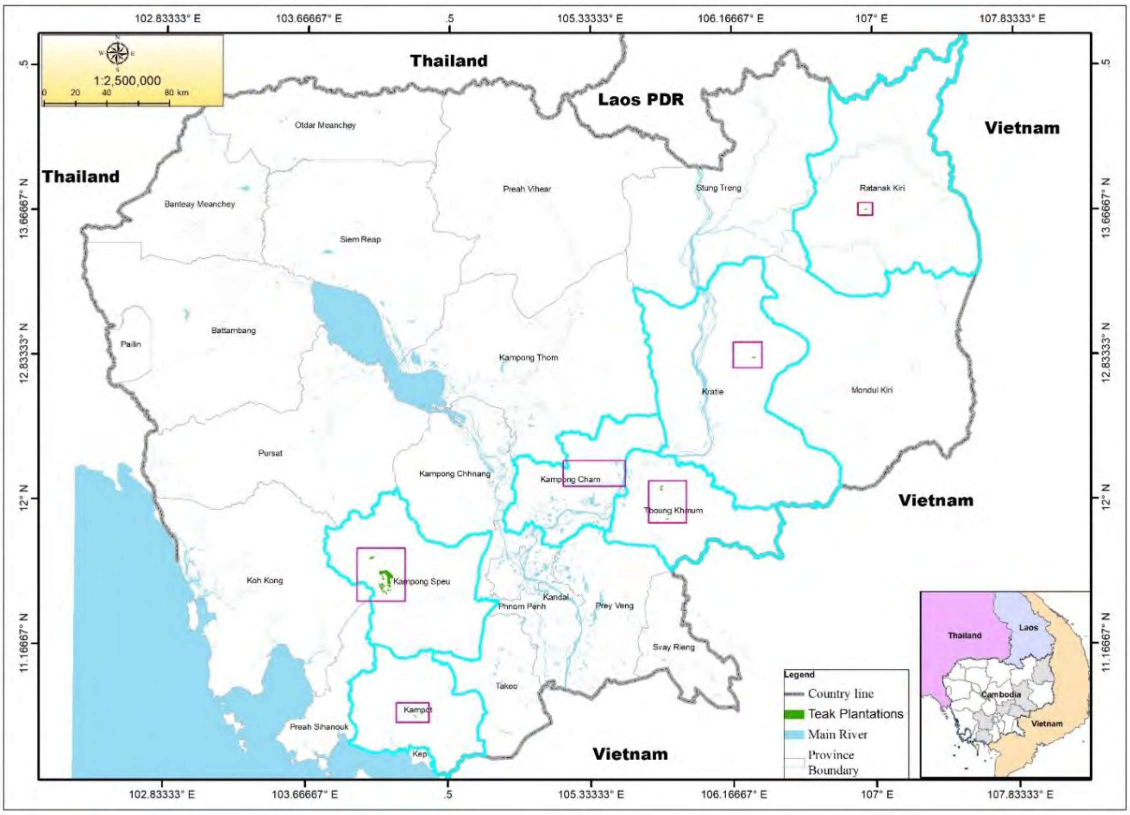


Figure 5-1 Map showing disperse teak plantations in Cambodia

Photo 5-3 Measuring and Monitoring of the Target Teak Demonstration Plots belonging to Mr. Keo Kosal, the owner of a private teak plantation in Han Chey commune, Kampong Cham Province

Silvicultural practices and teak wood products

The various conditions that may affect the growth of teak include climate different between the regions, application of cultivation techniques (space and cropping systems), silvicultural techniques including pruning and thinning, and maintenance such as fertilizer application to teak plantations. Therefore, the cycle of a business can also vary according to the growing status of teak trees. In India, the average dbh range of teak growth is 11.7-14.7 cm at the age of 10, 27.4-38.4 cm at 30 years old, and between 45.0-60.7 cm at 60 years old (Tewari, 1992). In Vietnam, the mean annual increment (MAI) of teak in the first 20 years increased 4.0-11.5 m^3/ha/year (MoF, Vietnam). In Lao, the MAI range of dbh was between 1.14-1.34 cm/year at the age of 1-15 years, 1.02 cm/year at 16-25 years and grew more slowly at 0.7-0.4 cm/year from 26 to 40 years old (MoAF, Lao). In Indonesia, the MAI of teak was about 14 m^3/ha/year at 5 years of age (average diameter at 18 cm) (Rimbawanto, 2021). A study of teak plantations in India revealed that juvenility in plantation grown teak extends up to 15, 20 - 25 years depending on the property, growth rate and individual tree and plantation site, with a specific gravity of 0.63 between the ages of 13-35 and 0.64 at the age of 55 years (Bhat et al., 2001).

In Cambodia, government-owned teak plantations have been established since 1993 and at that point of time, the effectiveness of silvicultural practices was not taken into consideration. The spacing of planting teak was just 2x2 m. or 2x3 m. interval which limits the growth of teak trees and low economic returns. The measurement of 20 teak trees planted in 1993 at Teuk Chhar Teak Plantation provided small dbh, (27.62 cm, on average) at the age of 28 years, or the mean annual increment (MAI) of dbh growth was approximately 1 cm., while the average MAI of dbh of another 20 teak trees planted in 1996 in the same location was 25.56 cm at the age of 25 years. Another measurement of teak dbh at Teak Wood Furniture Cambodia in Ratanakiri province provided average dbh around 20 cm, planted in 2001 (20 years old) with 2x2m. spacing, which did not show significant difference between locations. However, the MAI seemed to be similar to those in the above-mentioned countries.

Photo 5-4 A study comparing the growth between planting without pruning and pruning and maintenance (thinning and pruning) and monitoring the mean annual average growth of teak (mean annual increment-MAI)

Recently with financial support from ITTO Teak Project in Mekong, demonstration plots on teak silvicultural practices were established with 10 plots and 12 plots located in Kampong Cham and Kampong Speu provinces, respectively, and 11 of those plots in each province were treated with pruning, while another 11 was control plots (non-silvicultural practice).

The measurements of teak demonstration plots were conducted four times-at baseline in October 2019, the second measurement in early June 2020, and the third in October 2020 (Photos 5-3, 5-4). Consequently, the yearly growth of teak dbh with pruning treatment was 2.19 cm, which was significantly higher than that of the control plots that was just 0.55cm (the trial plots in Kampong Cham). For demonstration plot in Kampong Speu province, the teak growth of pruning treatment and the control appeared non-significant in terms of both dbh and height.

The density and spacing of teak planting, which significantly affect the growth of teak are taken into consideration to coincide with both economic effectiveness and trials. The Grandis Timber Co., Ltd. that has planted teak since 2014 and Teak farm that started establishing teak plantation since 2018 set up demonstration plots to conduct experiment of teak growth at different treatments such as various intervals tested, silvicultural techniques applied, and intensive maintenance undertaken. The measurement conducted in 2020 revealed that the average DBH of teak planted at Grandis Timber Co., Ltd. was 6.35 cm. (3.2x2.5 m. of spacing) and 8.41 cm. (4.0x2.5 m. of interval) with the age of 2 and 3 years- old, respectively.

Currently, the 8-10 years of teak cultivars can be harvested using intensive silvicultural practices applied at teak plantations in Kampong Speu province by Teak Farm and Grandis Timber and through genetic improvement and cloning, like what has been done in Indonesia.

Photo 5-5 Nursery breeding, experiment in the nursery, using technology (Sensor) to record for monitoring the growth of teak trees at Teak Farm's in Kampong Spure Province (Credit: Teak Farm, Cambodia**)**

The demonstration plots of teak trees planted in 2018 (1,5-2 years old) at Teak Farm showed a rapid growth of teak with 12 cm. in DBH and 8 m. in height (Photo 5-5). Teak wood is medium density, hard, yellowish brown, fragrant and oily that repel insects. It is one amongst other local timber species that are considered good luxury wood for construction, furniture, home decoration, musical instruments, railroad, etc. (Phon, 2000; Orwa et al., 2009).

The price of teak sawnwood in the local market (Cambodia), as assessed by the owners of local private teak plantations and teak wood processing factories varies between 800-1,500 USD per cubic meter, depending on the quality, length, and diameter of the wood. This price seems to be higher than in international market, and that may be a reason teak is uncommon in most of the local wood processing factories or handicrafts.

Photo 5-6 Teak products--wooden furniture made of teak in Lamphat district, Ratanakiri Province (Credit: Mr. ChhunVirak)

Since there is not much supply of teak wood originated domestically from various sources in Cambodia, the made-of-teakwood products and furniture could hardly be found both in local markets and at wood processing factories. In 2021, a wide range of made-of-teak wood products are seen extensively promoted for marketing sales on social media (Photo 5-6). Teak Wood Furniture Cambodia is a local wood processing factory that has just started its own wood processing business for 6 months, and all teak wood products are processed from teakwood harvested from their own teak plantation established since 2000. There are numerous types of teak wood products getting purchasing orders, including round and rectangle wooden tables, foldable wooden tables, wooden armchairs, complete set of wooden sofa, many kinds of wooden furniture, wooden decoration material for construction, long wooden dinner tables, wooden beds, teak plywood, and other types of teak sawnwood. Such business is flourishing well with piles of pre-orders in a satisfactory manner.

Challenges for Teak Plantation Development

There are some challenges that may undermine the development of teak plantation in Cambodia, including the shortcomings as follow:

- Investment in teak plantations requires considerable capital for start-up and operation which is a long-term business (at least 20-25 years). Some teak plantations already established many years ago have experienced lack of resource for the long duration business cycle. Even though they could collect economic benefits from some short-term cash crops during the first few years and once the canopy growth of teak trees reach one another, another 15-years was needed depending on market demand until teak could be harvested at suitable/accepted DBH;

- Lack of financing with low interest rates in the long run. Teak plantation needs substantial financial investment, especially in the first few years for establishing teak plantation. Then maintenance and preventative fire protection measures are quite necessary. Many small- and medium-scale investors are not capable of seeking long-term financing/loan from the existing commercial banks and Micro Finance Institutions (MFIs) due to the ambiguity of both investors and bankers in relation with uncertain economic return and fluid market fluctuations; few raised their concerns about break-even point (BE) in which duration and internal rate of return (IRR) must be ensured, otherwise their business would become bankrupt in the halfway of operation.
- Poor knowledge on techniques for improving and conserving genetic resources through silvicultural practices to foster the growth and quality of teak, and to improve the teak market supply chain; some teak plantation owners complained about having no expertise resources although they have enough capital and strong interest in such area of investment.
- There is sufficient technology development and innovations in the production and wood processing industry (especially made-of-teak wood products) to add value to wood products (post-harvest) for export and to compete in international markets (value chain).

Promotion of Private Teak Plantation

There is no specific incentives related to teak plantation investment, but the below enabling policies and regulations are for the promotion of private forest plantation and tree plantation development in Cambodia.

There are a number of specific incentives stated in the laws, sub-decrees and regulations in Cambodia for incentivizing and supporting forest plantation establishment and development. The incentives include royalty exemption, export tax reduction, and other taxes and fees.

Large-scale investment in forest plantations establishment and development on public forest land has been initially promoted through public-private partnerships. In 2017, this was further promoted through the Declaration on Tree Plantation Development that facilitates the procedure of private forest registration and encourages private sector involvement, especially on legal private land. To contribute to the achievement of the sustainable development goal by which forest cover would be maintained at 50% by 2030 as defined as the national target in the Framework for Cambodian Sustainable Development Goals, the Royal Government of Cambodia (RGC) has promoted the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and promote afforestation and reforestation. With the most recent declaration in the Agricultural Strategic Development Plan (ASDP) 2019-2023, the Forestry Administration has set a target of at least 10,000 ha of forest plantations to be established annually, inclusive of 9,000 ha by the private sector. It also plans to distribute 10 million tree seedlings per year under its Conservation of Genetic Resources from Forest and Establishment of Seed Sources for Planting Program. In pursuit of this ambitious goal, the Forestry Administration has identified degraded forests and other degraded lands that are available for restoration and introduced initiatives for investing in the establishment of private forest plantations on state land by forging partnerships between various private sector entities.

In September 2005, RGC issued a Sub-decree on the implementation of the Amendment to the Law on Investment. In this regard, section 2 of Annex 1 of the Sub-decree sets the minimum amount or other conditions of investment projects in various fields, which are required for granting the incentives. Production of furniture and fixtures, that do not use natural wood and the production of paper and paper products with capital investment larger than USD

500,000.00 are among the fields which are eligible for incentives such as profit tax exemption, duty free import of production equipment, construction material and 100% exemption of export tax.

Granting of large-scale plantation: A Sub-decree on Economic Land Concessions was issued on December 27, 2005, that provides the criteria, procedures, mechanisms and institutional arrangements for initiating and granting new economic land concessions, for monitoring the performance of all economic land concession contracts, and for reviewing economic land concessions entered into force prior to the effective date of the sub decree for compliance with the Land Law of 2001. Economic land concessions are granted to grow food and agro-industry crops including tree plantation, animal farm and aquaculture, construction of enterprises and factory facilities as well as instalment of equipment for processing of domestic raw materials.

The FA's efforts to create enabling conducive environment to develop plantation forestry has focused on multi-purpose tree plantations, which have a potential to supply domestic timber needs, increase incomes of local communities, and improve the environment through watershed protection and erosion control. These plantations will be developed to meet current and future market demands, taking cognizance of the need to protect the environment. Species considered include *Dipterocarpus alatus*, *Hopea odorata*, *Azadirachta indica*, rubber trees, *Eucalyptus camaldulensis*, *Acacia auriculifomis*, *Acacia mangium* and *Sesbania grandiflora*.

In 2012, the Ministry of Agriculture, Forestry and Fisheries and the Ministry of Economy and Finance issued a Joint Declaration on the Provision of Public Service associated with the forestry sector, especially fees and permits for forestry. The specific services stated in the Declaration include service fee for export of timber and non-timber forest products, permits for transportation, transport quotas, establishment of a timber depot to sell, distribute forest products & by-products, establishment of a forestry industry, sawmill, or forest products & by-products processing facility, use of any type of chainsaw to harvest forest products & by-products, premium (reforestation, forest maintenance and export fee) for all wood species, detailed service fees charged on timber and non-timber forest products is in Table 5-2.

Export tax for timber and non-timber forest products is fixed at 1% of the total cost in the permit (FoB reference price). Since log exports are currently banned, these taxes apply only to timber and non-timber forest products.

Table 5-2 Service fee for timber and non-timber forest products

Description	Service fee (USD)	Valid (year)
1. Timber and non-timber export tax	1% of the total cost in the license	Date in permit
2. Permit for timber and non-timber forest products		
– *Transport quotas*	25	1
– *Transportation*	10	Date in permit
– *Establishment of a stock place to sell, distribute and processing enterprise*	250	1
– *Establishment of a forestry industry and sawmill*	250	1
– *Use of chainsaw (per unit)*	15	1

Description	Service fee (USD)	Valid (year)
3. Reforestation	2.5/m^3	
4. Forest maintenance fee	5% of timber and NTFPs	

In order to encourage participation in tree planting and development as plantations, Article 46 of the Forestry Law (2002) states that "Individuals who plant trees on private land or on state forest land that has been granted the right to use have the right to maintain, develop, use, sell and distribute their products," and subsequently, the Rules on private forests have been promulgated by Prakas of the Ministry of Agriculture, Forestry and Fisheries to encourage individuals to cultivate and maintain plantations.

Recently, the Ministry of Agriculture, Forestry and Fisheries has allowed the Forestry Administration to plant fast-growing tree species such *Acacia sp., Eucalyptus* sp.*, and Tectona grandis* (Teak) as state forest plantations from 2020 onward. The aim is to ensure the sustainability of fuelwood supply for domestic consumption and the market demand for industrial processing.

In this context, the Forestry Administration has developed and released a Guideline for Site Selection and Tree Planting in Cambodia since 2005. The FA also provides an inclusive approach for practitioners and investors on how to prepare plans for tree planting, including sites identification, to ensure their success in forest plantation establishment and development.

In 2017, the Ministry of Agriculture, Forestry and Fisheries issued a Prakas on the "Private Forest Rules" that sets out the scope, requirements and procedures in the private forest registration process in Cambodia, classifying private forests according to the size of land planted or proposed, as well as outlines the many benefits that private forest owners receive and are encouraged. In this respect, the Forestry Administration would provide technical training services for afforestation and plantation management. Transportation of wood products originating from private forests to supply customers or the local market does not require a letter of permit (LP). Prior to harvesting timber in a private forest plantation, the owner of the private forest shall notify the competent local forestry administration in writing the harvesting activities undertaken and be responsible for inspecting the amount of timber collected.

However, Article 61 of the Forestry Law states that "the rules for granting the right to use state forest land for afforestation shall be determined by sub-decree", by which planting trees on degraded forest land where partnership in planting trees between the State and the private sector (Public Private Partnership (PPP) shall be authorized by the Royal Government of Cambodia as referred to a letter No. 120 S.C.N.K.S. dated 08 February 2017 of the Office of the Council of Ministers.

Private forests are defined as plantations or trees that grow naturally on land that is registered and privately owned under state valid procedures and laws. Private forest refers to plantation established by natural persons or private juridical persons who own land on their private land with the right to occupy in accordance with the land law and are registered as private forest according to the regulations of the Forestry Law and the Prakas No. 327 PRK dated 26 May 2017 on the Private Forest Rule.

With the current practices of establishment and registration of private forest plantation in compliance with forestry policies, laws and regulations, the MAFF promulgates the

Declaration on the Establishment of Private Forests to promote and incentivize individuals or juridical persons to plant trees on their own legally acquired land as a means of increasing timber production and fuelwood supplies for domestic consumption and export. The provisions of the regulation elaborate the procedure, legal requirements, and processes from application to harvesting of the tree plantations.

Private forests are categorized according to land sizes, as follows:

(i) household private forest: less than 10 ha;

(ii) small-scale private forest: 10-100 ha;

(iii) medium-scale private forest: more than 100 ha to 1,000 ha; and

(iv) large-scale private forest: more than 1,000 ha.

The guidelines provide guidance to assist landowners or juridical persons wishing to register their private forests, either plantations or natural plantations covering:

- the process of establishing and registering private forests;
- knowledge and skills in caring for private forest plantations;
- effective monitoring of the progress of responsible private forest management; and
- the importance of plantations and the potential of private plantations in improving the livelihoods of local people and communities, as well as contributing to socio-economic development and environmental protection.

The Guidelines on Private Forest Registration emphasizes the incentives to encourage the establishment of small-scale private tree plantations as set forth in chapter 1. It stresses that the Council of Ministers on behalf of the Royal Government of Cambodia issued a letter No. 1704, dated November 18, 2019, on reducing the export tax rate on timber products originating from tree plantations to encourage tree-planting investors as such below benefits as:

- 50% export tariff reduction on wood products sourced from domestically planted trees or local tree plantations;
- The imposed export tax of all furniture and other finished wood products made of locally grown wood is state-in-charge.
- The expertise authority shall certify the export license with the scientific and local names of the timber species and shall certify it as "locally grown timber" or "a wood product made of domestically-gown-tree".

A natural or juridical person who planted trees on private land or state forest land that has been granted the rights to use that land has the rights to maintain, develop, use, sell and distribute their products derived from their tree plantation. In addition, a natural or juridical person who owns private land on which trees have been planted and registered as a private forest shall hereby receive many incentives from the Royal Government of Cambodia, such as technical advices, not mandatory for premium payment, and those that have been set forth above.

Conclusions and Recommendations

Teak plantations not only provide forest cover, land cover, prevent erosion, restore soil erosion and wilderness, but agroforestry practices (especially degraded forest areas in community forests) and small-scale private plantations will help contribute forest rehabilitation through afforestation and private forest plantations. The agricultural crops mixed with teak plantation will not just provide short-term profit during the course of teak plantation, but also improve food security through the cultivation of maize, soybeans, cassava, and intermittent weeds will be easily controlled. The intercrops harvest from teak plantation can increase economic productivity for local communities in both the short and long-term. In addition, teak plantations will play an important role in contributing to the supply of sustainable construction timber in rural areas, especially the wood processing, furniture and wood industries, which can help reduce the dependencies on natural forest resources.

There are some recommendations to create a conducive environment for teak plantation development and promotion of teak plantation investment as follow:

- Conduct further researches on techniques for the improvement and conservation of genetics, teak, agroforestry and silvicultural practices, plantation management, growth models, policy and technical recommendations, information on price trends and supply of teak wood in the international market.
- Develop modalities for public-private investment in forest plantation establishment, especially teak plantation and teakwood product value chain, facilitate timely access to market information, especially on prices in the international markets.
- Enhance technical capacity and human resource related to improvement and conservation of genetics, teak, agroforestry and silvicultural practices, plantation management, market and value chain, and development.

References

Allouard, P. (1947). *Enlargement of Reforestation Modes by Intercalary Agricultural Crops*. Birth of Agroforestry in Indochina. Pierre Allouard, 1952. engineer from the Ecole Forestière de Nancy, served in Cambodia as 1930 to 1947.

Alvarado, A. (2013). Condiciones de sitio y la silvicultura de la teca. In *Plantaciones de TecaMitosy Realidades*, (eds. R. Camino & R.P. Morales (eds.). CATIE, Turrialba, Costa Rica.

Bailleres, H. & Durand, P. Y., (2000). Non-destructive techniques for wood quality assessment of plantation-grown teak. *Bois et Forêts des Tropiques,* 263 (1), 17-29.

Bhat, K. M., Priya, P. B. & Rugmini, P. (2001). Characterisation of juvenile wood in teak. *Wood Science and Technology,* 34, 517-532.

Council of Ministers. (2019). *Reduction of Export Fees for Products and Processed Products from Forest Plantation in Cambodia*, Cambodia.

FAO. (2009). *Global Forest Resources Assessment 2010.* Brazil Country Report, Rome.

FAO. (2015). *Global teak trade in the aftermath of Myanmar's log export ban.* In FAO Planted Forests and Trees Working Paper FP/47/E. (eds. Kollert, W. & Walotek, P.J.). Rome, Italy. http://www.fao.org/forestry/plantedforests/67508@170537/en/

Forest Resources Department. (n.d.). *Management of Teak Plantations*.Chiang Mai University, Thailand. https://www.fao.org/3/AC773E/ac773e08.htm#TopOfPage (accessed 10 July 2021).

ITTO. (2020). TTM Report 24 (7): 1-15 April 2020.

Kollert, W. & Cherubini, L. (2012). *Teak resources and market assessment 2010*. FAO Planted Forests and Trees Working Paper FP/47/E, Rome.

Kollert, W. & Kleine, M. (eds.) (2017). *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources*. IUFRO World Series Volume 36, Vienna. 108 p.

MAFF, MoEF & MoC (2009). Joint Ministerial Declaration on Imposition of Standing Timber Royalties for National Revenues, RGC

Ministry of Agriculture and Forestry (n.d.). *Teak in the Lao People's Democratic Republic*, Lao. http://www.fao.org/3/AC773E/ac773e0e.htm (accessed 10 July 2021)

Ministry of Forestry (n.d.). *The management and prospects of teak in Vietnam*, Vietnam. https://www.fao.org/3/AC773E/ac773e0i.htm (accessed 10 July 2021).

Narong, N. & Sobon, K. (2014). *Review of biological and silvicultural characteristics of timber trees planted in Cambodia*, Cambodia

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. & Anthony, S. (2009). Agroforestree Database: a tree reference and selection guide version 4.0. World Agroforestry (ICRAF) . Nairobi.

Pandey, D. & Brown, C. (2000). Teak: a global overview. An overview of global teak resources and issues affecting their future outlook. *Unasylva,* 51(201), 3–13.

Phan, D. P. (2000). *Dictionary of Plants Used in Cambodia*. Olympic Publish House, Phnom Penh.

Rimbawanto, A. (2021). *Teak Community Forests for Improving Livelihoods*. ITTO-BMEL project, 3rd Webinar 29th March 2021

Royal Government of Cambodia. (2001). Land Law (2001)

Royal Government of Cambodia. 2000. Sub-Decree on Economic Land Concession (2000).

Royal Government of Cambodia. (2002). Law on Forestry (2002).

Tewari, D.N. (1992). *A Monograph on Teak* (*Tectona grandis* Linn. f.), Int. Nat. Book Dist. Dehra Dun, 479p.

The Ministry of Agriculture, Forestry and Fisheries. (2019). Agricultural Strategic Development Plan (ASDP) 2019-2023. Phnom Penh, Cambodia.

The Ministry of Agriculture, Forestry and Fisheries. (2017). Prakas on Establishment of Private Forests. Phnom Penh, Cambodia.

The Royal Government of Cambodia (2019). Framework for Cambodian Sustainable Development Goals. Phnom Penh, Cambodia.

Thulasidas, P. K., Bhat, K. M. & Okuma, T. (2006). Heartwood colour variation in home garden teak (*Tectona grandis*) from wet and dry localities of Kerala, India. *Journal of Tropical Forest Science,* 18, 51-54.

Chapter 6: Teak Plantations in Vietnam

Dang Thinh Trieu, Tran Lam Dong
and Nguyen Van Bich

Abstract

Teak, introduced to Vietnam in early 20th century, has high adaptation to a wide range of climate condition from the North to the South in Vietnam. It can be planted as a homogenous plantation, as agroforestry crop, and as enrichment planting in the deciduous degraded dipterocarp forests across Vietnam. Teak has been planted mainly as a monoculture plantation (89.3%) and only occasionally as mixed species plantation (10.7%). The productivity of teak in Vietnam ranged 7-16 m^3/ha/year across different ecological conditions. The economic return of teak plantation is significantly higher compared to those of short rotation species such as acacia and eucalypt. However, the challenges for development of teak in Vietnam are its long harvesting rotation and lack of improvement in seed resources. For development of teak in Vietnam, research on improvement of germplasm and establishment of the seed and mother material production areas is highly recommended. Research on improvement of silviculture technology to boost its growth ability which shorten the harvesting rotation is also very important, especially when it can be used as a demonstration model to encourage tree growers. For smallholders who cannot afford to invest in long-rotation crops, teak based agro-forestry is a potential model which can help them earn significant incomes in the years before harvesting. Although teak timber value is much higher than acacia and eucalypt timber in Vietnam, the value chain of teak timber in Vietnam is still disadvantaged in comparison with acacia and eucalypt timber. Research on value chain and promotion of using teak timber in the wood industry in Vietnam may increase the demand for teak timber and its plantations. This article reviews the history and describes the current situation of teak plantation in Vietnam. It provides the sound understanding on germplasms, silviculture management, the potential and challenges, those will be basic information for promoting development and teak plantation in Vietnam.

History of Teak in Vietnam

Vietnam has a total geographical area of *331,235 km², n*early three-quarters of which is in hills. Between 1943 and 1990, the years of wars and much destruction, Vietnam's Forest cover declined from 43% to just 27.2% (Jong et al., 2006). With sustained efforts over the past three decades the country's forest cover has now increased to 41.89% comprising 10.28 million hectares of natural forests and 4.4 million hectares of plantations (MARD, 2020). The increase of forest cover was mainly contributed by the expansion of plantations of more than sixty tree species that have been planted throughout the country. While more than 60% of the trees planted are of exotic Acacia and Eucalyptus, teak has also been planted in the regions of Northwest, Central Highland and Southeast Vietnam (MARD, 2014).

Teak is not native to Vietnam. It was first introduced to Vietnam in 1889 by the French and this introductory planting continued till 1910 (Dinh, 1964). Between 1939 and 1940, teak was planted extensively in many provinces from the North to the South (Quat, 1995). Some trees of this period are still found along the roads and parks in many towns and cities, but no clear records of the planting sites, extent of area covered, or the seed sources are available.

A teak plantation over 4 ha was established in 1952 in Central Highland (Do et al., 1995) but its seed source was also not recorded. A decade later in 1961 and 1962, teak plantations were established in Southeast Vietnam using seeds from Thailand and Laos (Do et al., 1995). The exact extent of area planted in that period is not known but about 166 ha of these plantations still survive which are now managed as seed production plantation in Dong Nai province extending over a total of 171 hectares (Do et al., 1995). Teak plantations were also established in 1960s in the mountainous areas in the North Vietnam (Dinh, 1995). Data related to their extent is not available, but it has been reported that 4532 kg of seeds collected from these plantations were used in raising fresh plantations (Dinh, 1995).

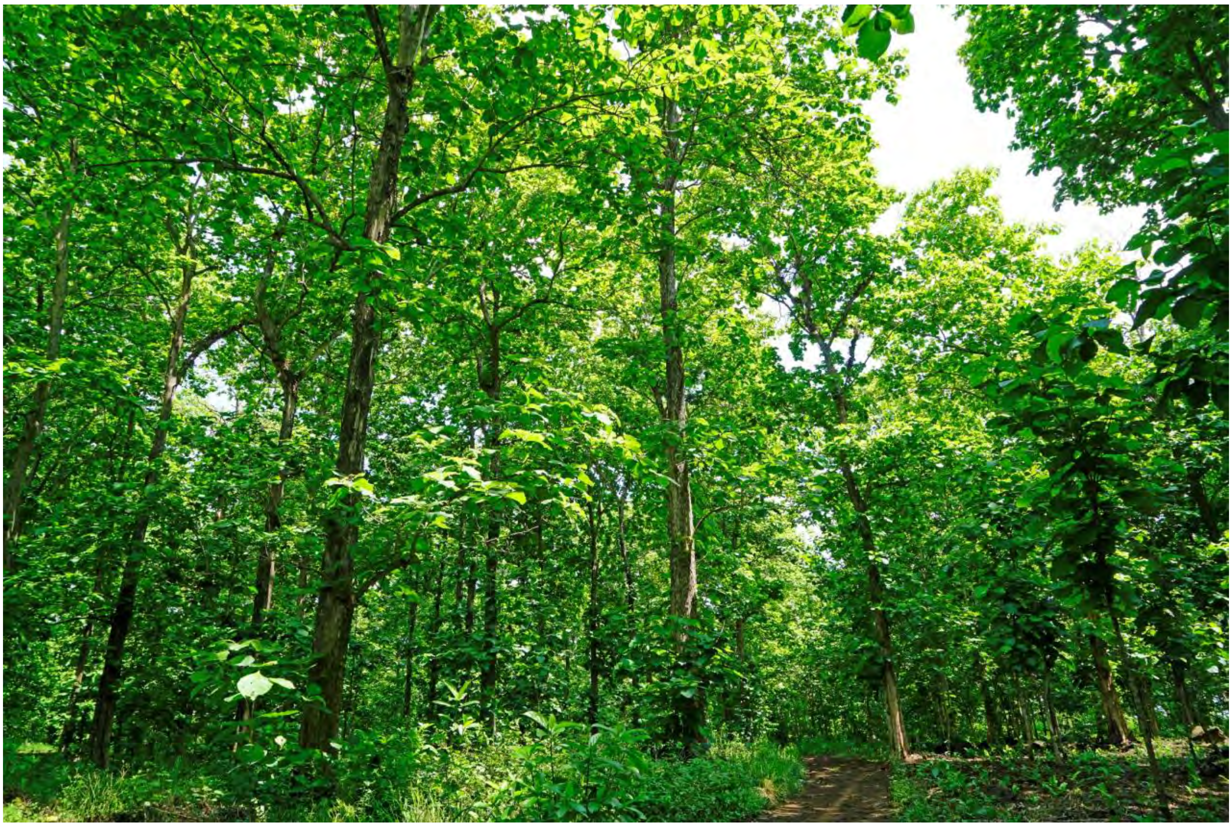


Photo 6-1 Teak seed production plantation established in 1961-1962 in Dong Nai province (Credit: Tran Lam Dong)

During 1986 - 1992, the total area of teak plantation in Vietnam was 4,670 hectares (Hoang, 1995), mainly in La Nga (Southeast) with 1,800 hectares (Dinh, 1995) and Buon Gia Vam (Central Highland) with 860 hectares (Phong & Sac, 1995). In December 1995, the Ministry of Agriculture and Rural Development (MARD) organized the First National Seminar on Teak Planting in Vietnam. Based on the presentations and discussion, the seminar participants recognized that teak was a potential tree species for planting in Vietnam with mean annual increment (MAI) ranging from 9-15m^3/ha/year. The workshop recommended that the MARD should have a plan of teak plantation development of 500,000 - 1,000,000 hectares in the following 10 - 15 years (Vietnam Forestry Association, 1995).

During the period 1993 to 2010, teak was in the list of the major tree species for planting in the two national large-scale forestation programs, namely Re-*greening Barren Land* and Hill (known as the 327 Program between 1993 - 1998) and Five Million Hectare Reforestation Project (known as the 661 Program between 1998 - 2010) (Jong et al., 2006). However, lack of research and extension on the species limited its large-scale adoption by the farmers.

Even though teak was one of the first forestry species chosen for planting in Vietnam and considered suitable for all sites across the country, the scale of plantations undertaken were not achieved as per expectation. Data from national forest inventory 2016 compiled in FORMIS II Project (2017) showed that only about 6,600 hectares, about 0.15% of the country's plantations, was under teak. This is negligible comparing with more than two million hectares of acacias, an exotic species introduced into Vietnam only in the 1980s.

Research on Teak in Vietnam

As mentioned above, teak was planted in Vietnam in the early 20th century mainly in the south and central highland which fell under the South Vietnam before the country's reunification in 1975 and not much information on the research conducted here on teak in those war years is available. Documents of early research on teak are accessible only from the North Vietnam.

Research on genetic improvement

In early 1960s, the forestry sector in the North Vietnam started establishing teak plantation. Since seed sources were insufficient initial studies were conducted on teak seed orchard. Branches from healthy well grown trees older than 20 years were used as mother material for grafting and 90% of grafted trees provided fruits. The seeds from those fruits were tested for weight and germination though no information about the production of seedlings from those seed lots are available now (Dinh, 1995).

After country reunification in 1975 the forestry sector continued to pay attention to genetic improvement in teak. In 1983, a provenance trial was conducted in Dong Nai province with 16 seed sources (Hoang, 1983). Unfortunately, the results of that trial are also not available. In 1993, a study on selection of teak plus tree and establishment of seed orchard in southeast Vietnam was conducted and growth performance including diameter at breast heigh (dbh), total height and bole height were assessed over an area of 350 hectares. Based on the dendrometry performance of the candidate trees 25 Plus trees were selected for establishment of seed orchard using grafting (Hoang & Nguyen, 1996). Teak Plus trees numbering 31 in total were also selected in central highland and southeastern region based on superior dbh and height growth compared to the means of standard deviation of the stands (Tran, 2001). A teak orchard was established based on seedlings and grafting sourced from the selected Plus trees. A trial was also conducted using indole *butyric* acid (IBA) in powder and liquid forms as rooting hormone (Tran, 2001). However, the results were not successful with rooting ratio ranging from 0 - 24.5%, depending on the source material and time of treatment. During the period 2006 to 2010, Doan & Le (2010) continued researching on tree improvement of teak with progeny tests. Three years after planting, the results indicated that the origin of the individual trees in the progeny test had significantly affected the performance of the families. The rooting was affected by hormone type, cutting age, and rooting media. The rooting ratios of the best treatment was more than 90%.

Research on silvicultural technique and others

Beside genetic improvement, silvicultural techniques for growing teak have also been developed in Vietnam. Based on experience and reference documents from overseas. Dinh (1995) developed silvicultural guideline including site preparation, planting season, and tending for teak plantation in the North and in 1994 research on silvicultural techniques for teak was carried out by Quat (1995) to establish teak plantations for veneer. The study examined the effects of soil type, soil preparation method, fertilizer type and type of plantation on the growth of the teak in Central Highland. Based on the results, a set of recommendations were developed for teak agroforestry model with soybean, sugarcane and peanut as cash crops in fertile soils, and protocols for ploughing and fertilizer application in infertile soils.

Teak was also used for testing enrichment of degraded dry deciduous dipterocarp forest in Central Highlands (Bao et al., 2018) and, five years into experimentation, teak was reported as a potential species for enrichment planting in degraded deciduous forests. Factors that affected the growth of teak include waterlogging, altitude, forest stand volume, soil type, percentage of sand, and P_2O_5 concentration in the soil (Bao et al., 2018). Based on assessment of growth of plantations in five sites and destructive analysis of 48 individual trees, Bao et al. (1996) classified soil index and estimated stock volume of teak in the Central Highlands. Yield tables of teak plantation were developed by Dao et al. (2001), based on dbh and total height of teak plantation in temporary sample plots in Central Highlands and Southeast regions. The timber yield tables were developed for teak plantations with 25 years and 50 years rotations suggesting yields ranging from 7 - 16 m^3/ha/year depending on rotation and planting.

Research on pest and disease of teak plantation

According to Bao et al. (1998), there were 10 pest species found in the teak plantations, but the most common were *Hapalia machoeralis* and termite. There are eight diseases found in teak plantation, of which fungus named *Vercitilium sp* was the most common. Leave of teak were also attached by *Olivea tectona* Thirum.

Current Situation of Teak Plantation in Vietnam

Plantation area

Teak plantation area in Vietnam is about 6,665 ha (FORMIS, 2017) spread across the country but with larger areas in the Southeast, Central Highland and Northwest (Figure 6-1). Teak plantations established during 1991-2001 under the 327 Program (1993 - 1998) and the 661 Program (1998-2010) occupy 50.3% of teak area plantations in Vietnam.

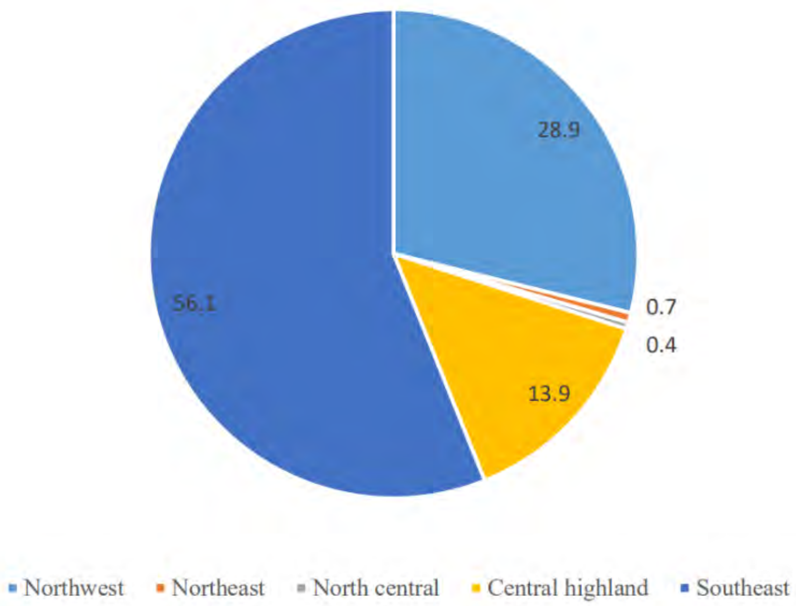


Figure 6-1 Distribution of teak plantation in Vietnam in 2016

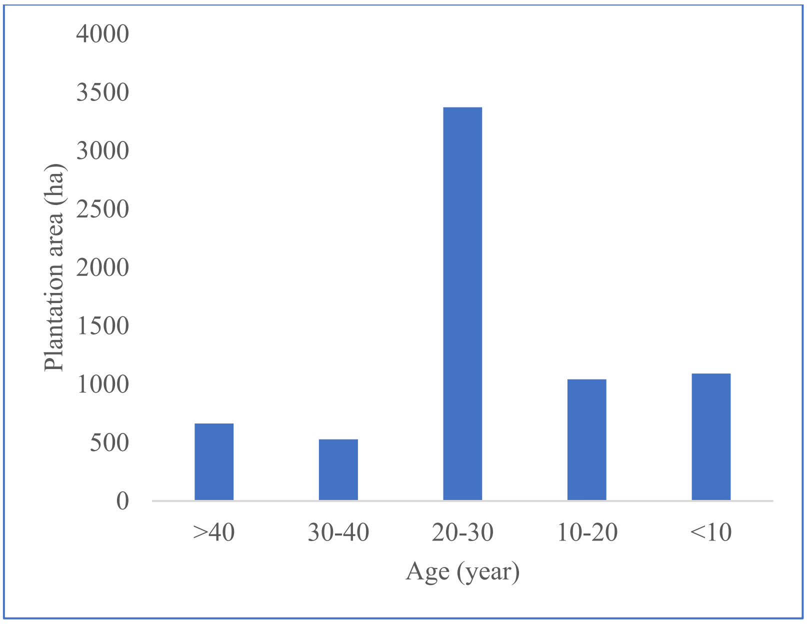


Figure 6-2 The area of teak plantation across age classes in Vietnam in 2016

Seed source

There have been several teak improvements studies in Vietnam as mentioned above, but no seed orchard were established. In 1990s, the Ministry of Agriculture and Rural Development decided to use a 166 ha of teak plantation raised between 1961 - 1962 as seed production area. As the result most young teak plantations in Vietnam established after 1990s have been using seeds sourced from that plantation. Some teak plantations, however, have also been established from unknow seed sources (VNFOREST, 2019).

Silviculture management

- Site selection

conditions described above, teak can Planting site conditions for teak in Vietnam have been described by the Vietnamese Academy of Forest Sciences (VAFS, 2005). The favorite temperature for teak is between 22ºC to 27ºC with average maximum temperature of the hottest month of 40ºC, minimum average temperature of the coldest month of 13ºC. Rainfall ranges from 1250 to 2500mm/year and 3-5 dry months of rainfall less than 40mm/month. Teak prefers a well-drained, sandy clay loam soils derived from basalts, granite rocks with more than 50 cm in deep and light neutral or slightly acid pH (6.5-7.5). With the site be grown in many regions across the country, especially in the Southeast, Central Highlands and Northwest with a total area of up to 1 million hectares.

- Plantation establishment

Teak plantations in Vietnam were established either as monoculture (89.3%) or mixed species (10.7%) with *Chukrasia tabularis*, *Azadirachta indica*, *Khaya senegalensis*, *Dipterocarpus sp*, *Acacia sp*, and *Pterocarpus macrocarpus* etc. Although no hard data for evaluating the mixed plantation with teak is available, mixed plantations have generally been observed as less successful. This failure is probably due to selection of species for mixed planting with teak. For example, in the mixed plantation of teak and *Acacia* hybrid in Thanh Hoa province (Northcentral), teak could not compete with Acacia three years after planting. As a result the forest owner removed Acacia but this resulted in almost teak trees becoming bent (Photo 2). This is due to high light competition between teak and acacia occurring at early stage, which led to weak ability to stand by itself after thinning acacia. Teak as the main tree in agroforestry models has been more successful. In northwest and central highlands of Vietnam where teak has been planted as a shade tree for coffee, plum or as intercrop with maize and upland rice it has provided significant benefits by way of wind breaks and additional income from timber after about 20 years.

Photo 6-2 Teak plants unable to stand straight following removal of *Acacia* hybrid in Thanh Hoa Province (Credit: Dang Thinh Trieu, 2019)

Photo 6-3 Agroforestry model of teak and coffee in Son La province (Credit: Tran Lam Dong)

- Growth and productivity of teak plantation

Measurements on increments of dbh in teak plantations of Vietnam ranged from 0.9 cm - 1.3 cm/year and on height ranged from 0.5 - 1.2 m/year, giving MAI ranging from 7.0 - 16 m^3/ha/year depending on age and site conditions (Table 6-1). It seems that the growth of teak in Vietnam was not much different among ecological regions.

Table 6-1 Growth and productivity of teak plantation in Vietnam

Ecological region	Age of plantation	Increment of dbh (cm/year)	Increment of height (cm/year)	MAI (m^3/ha/year)	Source
Northwest	13	1.1 - 1.2	0.9 - 1.0	Not available	Hoan & Hinh (2013)
Center Highland	40	0.9 - 1.3	0.7 - 1.2	7 - 16	Bao (1995)
Southeast	20	1.0	0.8	Not available	Nguyen (1995)
Southeast	51	0.9	0.5	Not available	Nguyen (1995)

Economic expectation

Dinh (1995) estimated that a 40-year teak plantation could bring the value of 1700 USD/year, much higher than that of eucalypt and acacia plantation in Southeast Vietnam. Bao et al. (1998) who estimated economic return of teak in Central Highland reports that IRR for 25 years (for medium timber size) and 50 years (for large timber) rotation was 18.0% and 15.0%, and the NPV of the rotation was USD 2,312.7 and USD 3.038.9, respectively. Investigation by Dang et al. (2019) in Thanh Hoa and Son La province has shown that, price of teak timber at harvestable age (between 20 - 30 years) was 8 - 14 times in comparison with price of acacia timber (harvest at 5 - 7-year-old).

Opportunities and challenges

Vietnam has developed acacia and eucalypt plantation regime for up to 4 successive rotations mostly providing wood chip, pulp, veneer and small saw-log timber. Some problems reported include low economic efficiency, risk of pests and diseases, and damage from natural disasters (Tran, 2018). In recent year, growers have been encouraged by the Government to produce large dimension timber. Teak is a potential tree species due to its wide adaptation across ecological condition throughout the country. Teak also meets the criteria of reducing the risk of pests and diseases as well as storm and wind resistance (Vietnam Forestry Association, 1996). The price of teak timber is increasing because of shortage of large size timber supply in Vietnam. The forest owners have already started using species other than acacia and eucalypt for their plantation, including teak and some native tree species. Teak promises to be a valuable and suitable tree species for large dimension timber plantation regime in Vietnam.

Major challenges for developing teak plantation in Vietnam include lack of capital resource of the growers and its long rotation (Trieu et al., 2020). This is especially so with smallholder forest owners who currently manage approximately 70% plantation area in Vietnam with average of 2-3ha per household. Lack of improvement of teak resource is another challenge for developing teak plantation in Vietnam.

Conclusion and recommendation

Vietnam has a long history of teak planting going back more than 100 years. However, the development of teak was limited over only about 6697 ha by 2017 distributed mainly in Northwest, Southeast and Center Highland. Teak has been planted mainly as a monoculture plantation (89.3%) and only occasionally as mixed species plantation (10.7%). The productivity of teak in Vietnam ranged 7-16 m^3/ha/year across different ecological conditions. The economic return of teak plantation is significantly higher compared to those of short rotation species such as acacia and eucalypt. However, the challenges for development of teak in Vietnam are its long harvesting rotation and lack of improvement in seed resources.

For development of teak in Vietnam, research on improvement of germplasm and establishment of the seed and mother material production areas is highly recommended. Research on improvement of silviculture technology to boost its growth ability which shorten the harvesting rotation is also very important, especially when it can be used as a demonstration model to encourage tree growers. For smallholders who cannot afford to invest in long-rotation crops, teak based agro-forestry is a potential model which can help them earn significant incomes in the years before harvesting. Although teak timber value is much higher than acacia and eucalypt timber in Vietnam, the value chain of teak timber in Vietnam is still disadvantaged in comparison with acacia and eucalypt timber. Research on value chain and promotion of using teak timber in the wood industry in Vietnam may increase the demand for teak timber and its plantations.

References

Bao, H. (1996). Growth and yield of teak plantation in Dak Lak. In: *Proceeding of First National Workshop on teak in Vietnam*, pp. 77-83. Hanoi, Vietnam.

Bao, H., Nguyen, V.F. & Nguyen, T.K.L. (1998). *Research on scientific basic to manage teak plantation*. Report of the project No B96-30-ĐT, University of Tay Nguyen, Vietnam.

Bao, H., Pham, C.T. & Tran, T. (2018). Assessment of enrichment planting of teak (*Tectona grandis*) in degraded dry deciduous dipterocarp forest in the Central Highlands, Vietnam. *Southern Forests: a Journal of Forest Science, 80*(1), 75-84.

Dang, T.T. & Tran, L.D. (2019). Current status of Teak planting in Thanh Hoa and Son La province. Unpublished report. Vietnam Academy of Forestry Sciences, Hanoi, Vietnam.

Dao, C.K., Bao, H., Dang, V.T., Phan, M.S., Bui, T.H., Hoang, V.T.& Nguyen, T.D. (2001). *Developing growth and yield tables for plantation of Eucalyptus urophylla, Acacia mangium, Tectona grandis, Pinus merkusii and checking yield tables of Rhizophora apiculate and Melaleuca cajupti*. Forest Science Institute of Vietnam, Vietnam.

Dinh, D.D. (1995). The experiences of planting teak in La Nga. In: *Proceeding of First National Workshop on teak in Vietnam*, pp. 72-76. Hanoi, Vietnam.

Do, D.S. & Nguyen, N.B. (1995). The solution for Agro-Forestry for teal in Central Highland. In: *Proceeding of First National Workshop on teak in Vietnam*, pp. 62-67. Hanoi, Vietnam.

Doan. T.M. & Le, S. (2010). *Tree breeding with Melia azedarach and Tectona grandis for large timber planting*. Project report. Forest Science Institute of Vietnam, Vietnam.

FORMIS. (2017). Project of Development of Management Information System for Forestry Sector - Phase II (*FORMIS* II). The Ministry of Foreign Affairs of Finland and the Government of Viet Nam.

Hoang, C, & Nguyen, T.H.T. (1996). *Selection of teak plus tree and establishment of seed orchard in Southeast*. Project report No. KN 03-03. Forest Science Institute of Vietnam, Vietnam.

Hoang, C. (1983). *Provenance trial of teak in Dong Nai*. Project report. Forest Science Institute of Vietnam, Vietnam.

Hoang, H. (1995). Opening speech of the chairman of Vietnam Forestry Association in the First Workshop on Teak in Vietnam. In *Proceeding of First National Workshop on teak in Vietnam*, pp. 7-8. Hanoi, Vietnam.

Jong, D.W., Do, D.S. & Treu, V.H. (2006). *Forest Rehabilitation in Vietnam: History, Realities and Future*. Center for International Forestry Research, Bogor., Jakarta, Indonesia

Lam, C.D. (1962). *Produce teak seedling using grafting*. Forestry Research Institute of Vietnam, Vietnam.

Lam, C.D. (1964). *Planting timber forests for industry*. Rural Publishing House, Hanoi, Vietnam.

Le, H.P. & Ho, V.S. (1995). Planting teak in Buon Gia Vam Forestry Enterprise. In *Proceeding of First National Workshop on teak in Vietnam*, pp. 68-71, Hanoi, Vietnam.

MARD. (2014). List of Main Species for Planting in Production Forest Land in Eight Forestry Ecological Regions (Decision No.4961/QD-BNN-TCLN (17/11/2014). In Vietnamese.

MARD. (2020). Announcement of the Current Status of the National Forest in 2019 (Decision No.1423/QD-BNN-TCLN (15/4/2020). In Vietnamese.

Nguyen, C.H. & Vu, T.H. (2013). Study on growth of teak (*Tectona grandis* Linn. F.) in Son La Province. In *Proceeding of 5th National Conference on Ecology and Ecological Resources*, pp. 1341-1350, Vietnam.

Nguyen, X.Q. (1995). Site selection and land use for teak plantation in Vietnam. In *Proceeding of First National Workshop on teak in Vietnam*, pp. 53-61, Hanoi, Vietnam.

Tran, L.D. (2018). *Conversion of Short-rotation to Long-rotation Acacia Plantation for Production of Saw logs. Report of the Science and Technology*. Research Project. Vietnamese Academy of Forest Sciences, Vietnam.

Tran, V.S. (2001). Selecting teak cultivar for Southeast and Central Highland. Information on Forest Sciences and Technology. *Forest Science Institute of Vietnam. 2*, 24-29.

Trieu, V,H., Pham, T..T & Dao T.L.C. (2020). *Vietnam Forestry Development Strategy: Implementation results for 2006-2020 and recommendations for the 2021-2030 strategy*. Occasional Paper 213. Bogor, Indonesia: CIFOR.

VAFS. (2005). Technical guideline on planting of Teak (*Tectona grandis* Linn. F.) http://vafs.gov.vn/vn/quy-trinh-ky-thuat-trong-rung-tech/.

Vietnam Forestry Association (1996). The recommendations In: *Proceeding of First National Workshop on teak in Vietnam*, pp. 100-101, Hanoi, Vietnam.

Chapter 7: Mapping of Natural Teak Forests and Teak Plantations in the Greater Mekong Sub-Region

Chakrit Na Takuathung

Abstract

This chapter assesses the status of natural teak forests that are the source of genetic diversity in teak, and teak plantations for which diverse high quality genetic material is in increasing demand. The data were gathered from the participating countries of ITTO's teak project for the up-to-date maps of teak natural forests and teak plantations of Cambodia, Lao PDR, Myanmar, Thailand and Vietnam. Largest extent of natural teak forest area occurs in Myanmar where they are managed under the Modified Myanmar Selection System (MMSS). In Lao PDR, the only natural teak forest left is in the northwest over an area of 1,100 ha. In Thailand, the natural teak forests are distributed in the north and the west with an area of 1.3 million ha. Attempts have been made to secure the status of natural teak forests in Thailand and Lao PDR by placing ban on logging. Teak has been extensively planted in all these countries. The highest extent of teak plantations is in Myanmar following by Thailand, Lao PDR, Cambodia and Vietnam spread over 411.7, 277.3, 29, 6.5 and 3.3 thousand ha, respectively.

Introduction

Teak (*Tectona grandis* L. f.) is a deciduous tree of the Lamiaceae family. Its wood quality makes it a high demanding species in the luxury market, construction industry and furniture manufacture (Kollert & Walolek, 2017). This species is one of the most important tropical timber both in natural and planted forests (Graudal & Moestrup, 2017). The growth of teak is controlled by many factors. Although it can be grown under a wide range of climatic conditions, the important factors with the optimum values are rainfall and soil moisture (1,250-2,500 mm/annum associated with a marked dry period of 3-5 months), temperature ranging from 27-36 °C during day time and 20-30 °C during night, bright light (75-95% of full day-light), with the soil conditions (soil derived from volcanic origins such as trap, basalt and granitic-gneiss) and soil pH 6.5-7.5 with a large amount of calcium (Kaosa-ard, 1981). Teak can grow faster in deep, fertile, well-drained soils and soil derived from limestone (Tanaka et al., 1998).

Natural teak forests cover the Indian Peninsula, Myanmar, northern and western Thailand as well as northwestern Lao PDR along the northern Thai border. Teak is distributed from 73°E in India to 104°30´E in Thailand and from about 25°30´ N in the Kachin State of Myanmar to its southern boundary from 9°N in India through 15°-16°N in Myanmar to 16°30´N in Thailand (Tanaka et al., 1998). The estimated area of natural teak forests in India, Lao PDR, Myanmar and Thailand is 29.04 million ha, almost half of which is in Myanmar (13.5 million ha). Teak was introduced to Java, Indonesia some 400 to 600 years ago (Pandey & Brown, 2000). As per FAO's teak resources and market assessment (Kollert & Cherubini, 2012), Myanmar, India, Thailand, and Indonesia dominate in the production of teak with more than 95% of the world's natural and more than 75% of the world's planted teak forests. The plantation area shows an increasing trend from 2.25 million ha in 1975 (Pandey & Brown, 2000) to 4.35 million ha in 2010 (Kollert & Cherubini, 2012).

It is speculated that genetic bottlenecks combined with selection pressures under different growing conditions have led to the formation of distinct landraces; this hypothesis is supported by results from international provenance tests (Hansen et al., 2017). The area and growing stock of natural teak forests in their natural habitat have been gradually decreased (Khaing et al., 2017). The log export ban in Myanmar, the main supplier of the world teak from natural forest, since 2014 has led to increased interest and investment in establishing and managing teak plantations (Kollert & Walotek, 2015). In this context, it is necessary to determine the status of natural teak forests which are the main source of genetic diversity and plantation areas - the source of genetic materials demand.

Material and Methods

1. Gathered data from the participating countries of ITTO's teak project for up-to-date maps of teak forest types and forest plantations in Cambodia, Lao PDR, Myanmar, Thailand and Vietnam. The data is defined according to the report of Kollert & Cherubini (2012) for all country representatives to follow the same direction (Table 7-1). The data includes GIS datasets of natural teak forests and teak plantations and its total estimated area. Where no GIS dataset was available, the raw data with Province names was utilized.

2. Synthesized and consolidated the datasets to prepare up-to-date natural teak forests and teak plantations with QGIS software and designed proper data visualization. Cambodia, Thailand and Lao PDR are visualized as polygons of forest and plantation while Vietnam is visualized as polygons of the province with the color.

3. In the case of Thailand, the distribution map of mixed deciduous forest with teak in 1990 reported by (Graudal et al., 1999) was overlayed with the mixed deciduous forest in 2018 reported by the Royal Forest Department and total forest fragmented areas that overlapped with the teak forest area in 2018 was estimated. The result of natural forest distribution was validated with the forest inventory data of THAIFORM project (Trisurat et al., 2020). The teak plantation data were derived from the Forest Industry Organization (FIO, 2021) and land development department (LDD) (Land Use Analysis Group, 2021). The general flow of the analysis procedure is shown in Figure 7-1.

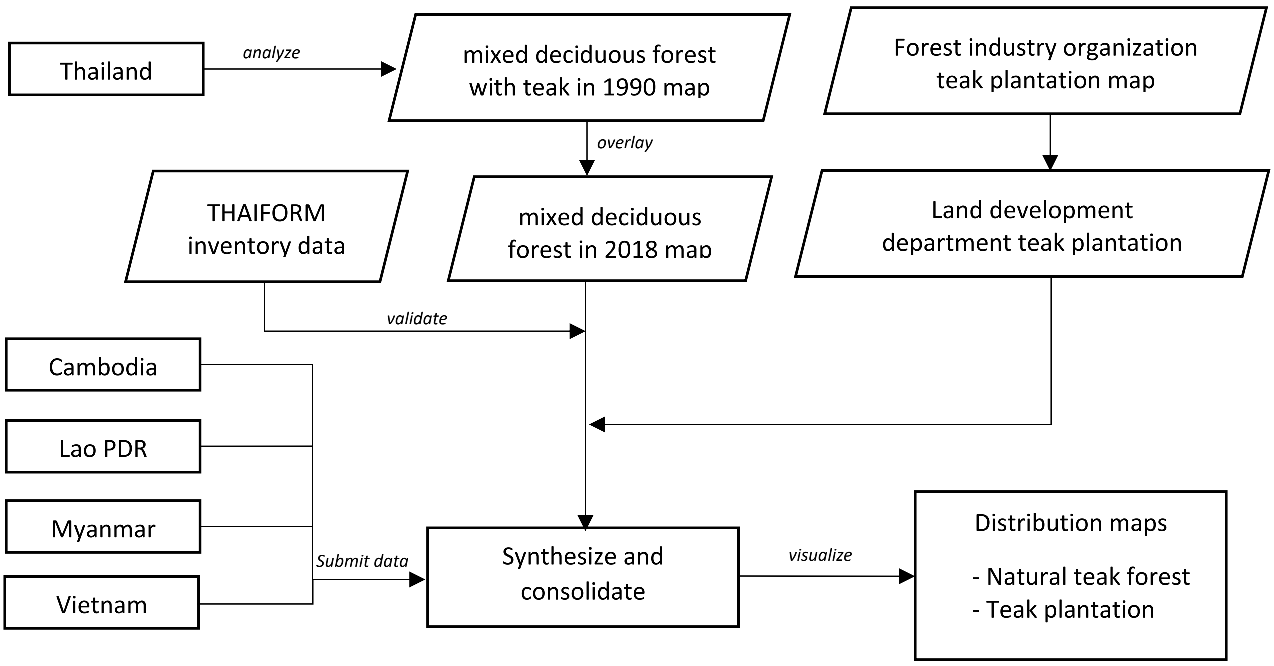


Figure 7-1 The general flow chart of the analysis procedure

Table 7-1 Definition of data

Types	Definition
Natural teak forest	Forest of native/indigenous species with a share of teak of 30 percent or more in its growing stock.
Teak plantations	Forest of teak established through planting or seeding for the production of wood or non-wood products and/or for the provision of environmental services. The share of teak in the growing stock is above 30 percent.

Sources of Data

We received data from the country representatives except for Myanmar as follows.

- Cambodia – Chheang Dany (Forestry Administration of the Ministry of Agriculture, Forestry and Fisheries)
- Lao PDR – Vongvilay Vongkhamsao and Bounchanh Mekaloun (National Agriculture and Forestry Research Institute (NAFRI)
- Thailand – Chakrit Na Takuathung and Pattama Sangvisitpirom (Kasetsart University).
- Vietnam - Dang Thinh Trieu (Vietnamese Academy of Forest Sciences -VAFS).

Results

Current Distributions in the GMS

The potential natural distribution area are derived from the current forest area overlayed by the natural distribution zone from Kaosa-ard (1981) (Figure 7-2). The area statistics of natural teak forest and teak plantation are presented in Table 7-2 and Table 7-3. The distribution maps by country are shown under the country topics.

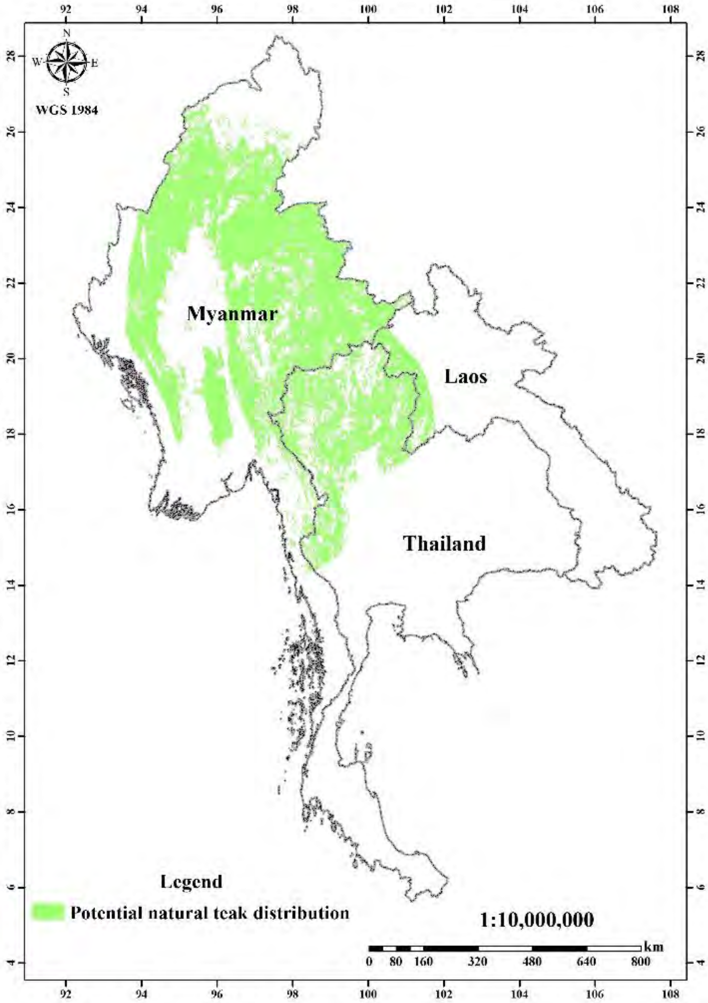


Figure 7-2 The potential natural teak distribution in 2021

Table 7-2 Area of natural teak forests (1,000 ha) as on 2021

Country/year	1954*	1976/1979**	1993*	2010**	Present
Lao PDR	-	70	-	1.5	1.1 (2021)
Myanmar	-	14,600	-	13,479	?
Thailand	2,324	5,850	1,880	8,744	1,353 (2018)

Remarks:
* after Sumantakul & Sangkul (1998)
**after Graudal & Moestrup (2017)

Table 7-3 Area of teak plantations (1,000 ha)

Country/year	1998*	2009**	2010**	2015**	Present
Cambodia					6.46 (2021)
Lao PDR		0	-	15	29 (2018)
Myanmar		0	390	390	411.712 (2020)

Country/year	1998*	2009**	2010**	2015**	Present
Thailand	806	836	128	836	277.288 (2021)
Vietnam					3.3 (2019)

Remarks**:** The numbers in the first row are the data published year
*after Sumantakul & Sangkul (1998)
**after Graudal & Moestrup (2017)

Cambodia

Natural teak forests do not occur in Cambodia, but the establishment of planted forests has been promoted by the Ministry of Agriculture, Forestry and Fisheries (MAFF) (Photo 7-1). The National Development Programme in Cambodia put efforts to create multipurpose tree plantations and to develop plantation forestry with the potential aim to supply domestic timber needs and increase the incomes of local communities. The main species being established include rubber, Eucalyptus spp., Acacia spp. and teak (Global Forestry Services et al., 2014). The plantations usually cover degraded lands or former forestlands that were somehow deforested a long period ago. During 1985-2006, forest plantations have been established over an area of 16,825 ha (Forestry Administration, 2008) most of which are in the six Provinces of Tbong Khmum, Kampong Cham, Kratie, Ratanakiri, Kampong Speu, and Kampot.

The main supply of timber in Cambodia comes from Economic Land Concessions (ELCs). One good example of the ELC project is the 70 years contract with a foreign company granting it concession over 9,820 ha in the rugged hills of Kampong Speu for replanting with teak (Becker, 2012). Besides block plantations of teak there is also scattered planting of 7.2 to 10 million teak trees across the country that would be equivalent of about 6,200 and 7,000 hectares of block plantations. Also, teak planting is sparsely distributed in agroforestry systems (small/household scale: 100-1,000 trees).

Data on teak plantation were obtained from respective provincial Forestry Administration cantonments and owners of private teak plantations, while the shape file of those teak plantations (on the map) was received through geo-referencing and tracking at the fields. The area of the shape file may be larger than the actual report, at 6,460 ha and 6,100 ha, respectively, and it is because the shape file takes into consideration both the land that has been cleared for planting teak and lands already planted with teak (Figure 7-3).


Photo 7-1 Teak plantations in Cambodia

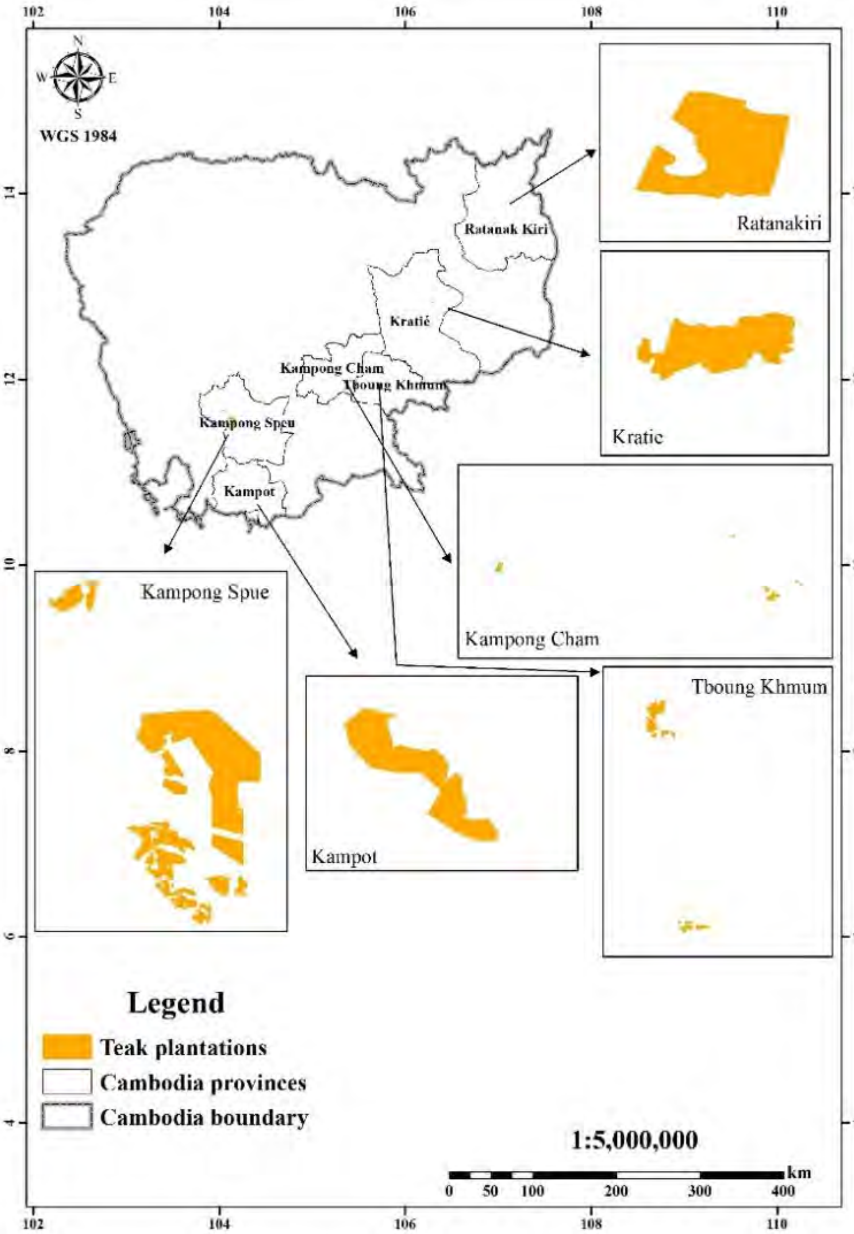


Figure 7-3 Distribution of teak plantations in Cambodia

Lao PDR

Teak is one of the most valuable tree species in Lao PDR. In the 1970s the country had about 70,000 ha natural teak forests, but in 2010 only about 1,500 ha are left (Graudal & Moestrup, 2017). They are mainly located in Provincial Protected Areas in Paklai District, Xayabuly Province in the Northwest (Photo 7-2) and are closed to logging. Data collected now suggests the current area may be only about 1,100 ha. Harvesting teak from natural forests is severely restricted by the government, and harvesting is largely limited to old logs left in the forest from earlier logging operations (Midgley, Mounlamai, et al., 2015). In addition, teak has been established by private companies and rural communities in plantations and agroforestry production systems (Photo 7-3). Large plantations of around 29,000 ha are located in the North in the Luang Prabang and Xayabuly Provinces (Figure 7-4). The small areas of teak plantations were also planted in Vientiane, Salavan and Champasack Provinces (Smith et al., 2018).

Photo 7-2 Natural teak forests in Xayabuly Province, Lao PDR

Figure 7-4 Teak plantations in Luang Prabang Province, Lao PDR
Source: Feuerborn (2018)

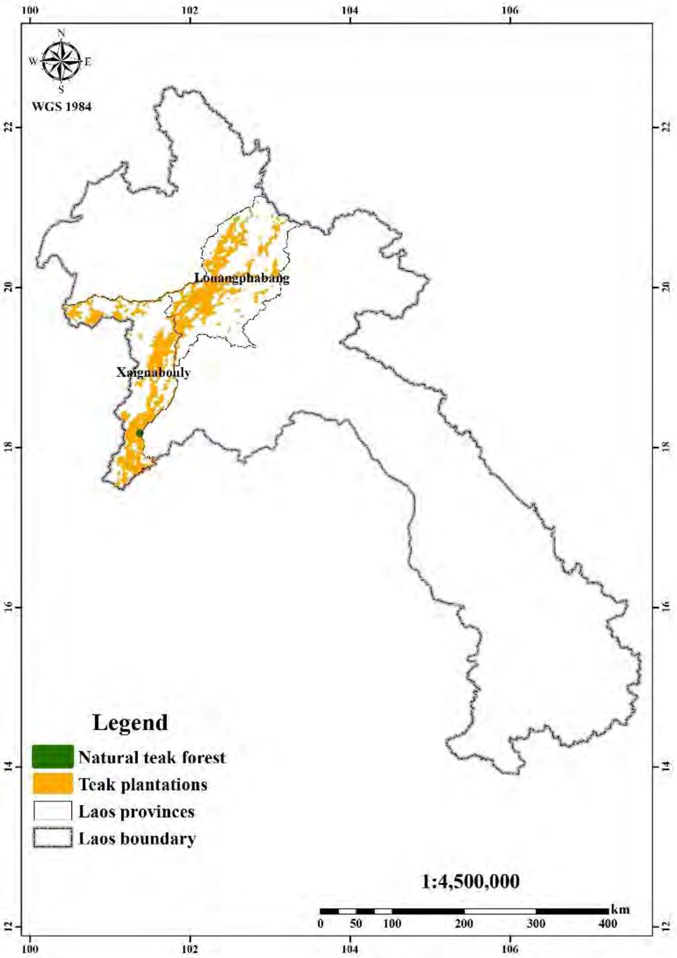


Figure 7-4 Teak distribution in Lao PDR

Myanmar

Myanmar is a teak heavyweight, playing a significant role in the global teak trade. It has the largest area of natural teak forests holding almost 50 percent of the 29 million ha globally and is the number one producer of teak logs in the world. Natural teak forests are traditionally managed under the Myanmar Selection System (MSS) and the Modified Myanmar Selection System (MMSS). After India and Indonesia, the country has the third-largest planted teak area in the world (about 390,000 ha) in 2010 (Kollert & Cherubini, 2012; Midgley, Somaiya et al., 2015).

Unfortunately, the current project could not get data from the official representative of Myanmar so there is no official project update on teak forest and plantation distribution map of Myanmar. However, as seen from Myanmar Forest Department publications the total extent of teak plantations in the country in 2020 is 4,11,712 ha of which government teak plantations are spread over 395,492 ha while private teak plantations cover 16,220 ha (Forest Department, 2020)

Thailand

Thailand has the second largest area of natural teak forests (after Myanmar) at an estimated 8.7 million ha (Kollert & Cherubini, 2012). There are no virgin teak forests left in Thailand. Selective logging has taken place in all native teak forests (Photo 7-4). The remains are fragments, mainly in a few protected areas (Graudal et al., 1999). The natural teak forest area in Thailand has declined as shown in Table 7-2. The area looks increasing in 2010 but it is likely an overestimate. As teak is generally limited to mixed deciduous forest, and the area of this forest type reported in

2000 and 2018 by the Royal Forest Department of Thailand (RFD) were 8.7 and 7.5 million ha respectively, so it is possible that all mixed deciduous forests were counted as teak bearing forests. In 2021, we used the distribution map of mixed deciduous forest with teak in 1990 reported by (Graudal et al., 1999) overlayed with the mixed deciduous forests in 2018 as reported the RFD. Calculated this way the sum total of all the forest fragments with teak in 2018 adds up to 1.3 million ha (Table 7-2). Validation by inventory data of THAIFORM project showed the accuracy of 79.3%.

A complete ban on logging in natural forests was introduced in 1989. The timber can be legally harvested only from plantations (Photo 7-5). Teak forest plantations were first established in Thailand in 1906 (Sumantakul & Sangkul, 1998). The plantation area reported was high in the past (Table 7-3). It could be due to the inclusion of replanting done in the natural forest under the conditions of Concession. The current plantation area in 2021 is 277,280 ha. The data are derived from Forest Industry Organization (FIO) which is the main teak plantation owner in Thailand and the small-scale plantation data from the Land Development Department (LDD)'s land use status report. The latter data might be of low accuracy as the teak area was not the main objective of the data analysis. The distribution of natural teak forests and teak plantations are shown in Photo 7-5.

Photo 7-4 Natural teak forests in Mae Hong Son Province, Thailand

Photo 7-5 Teak plantations in Kanchanaburi Province, Thailand

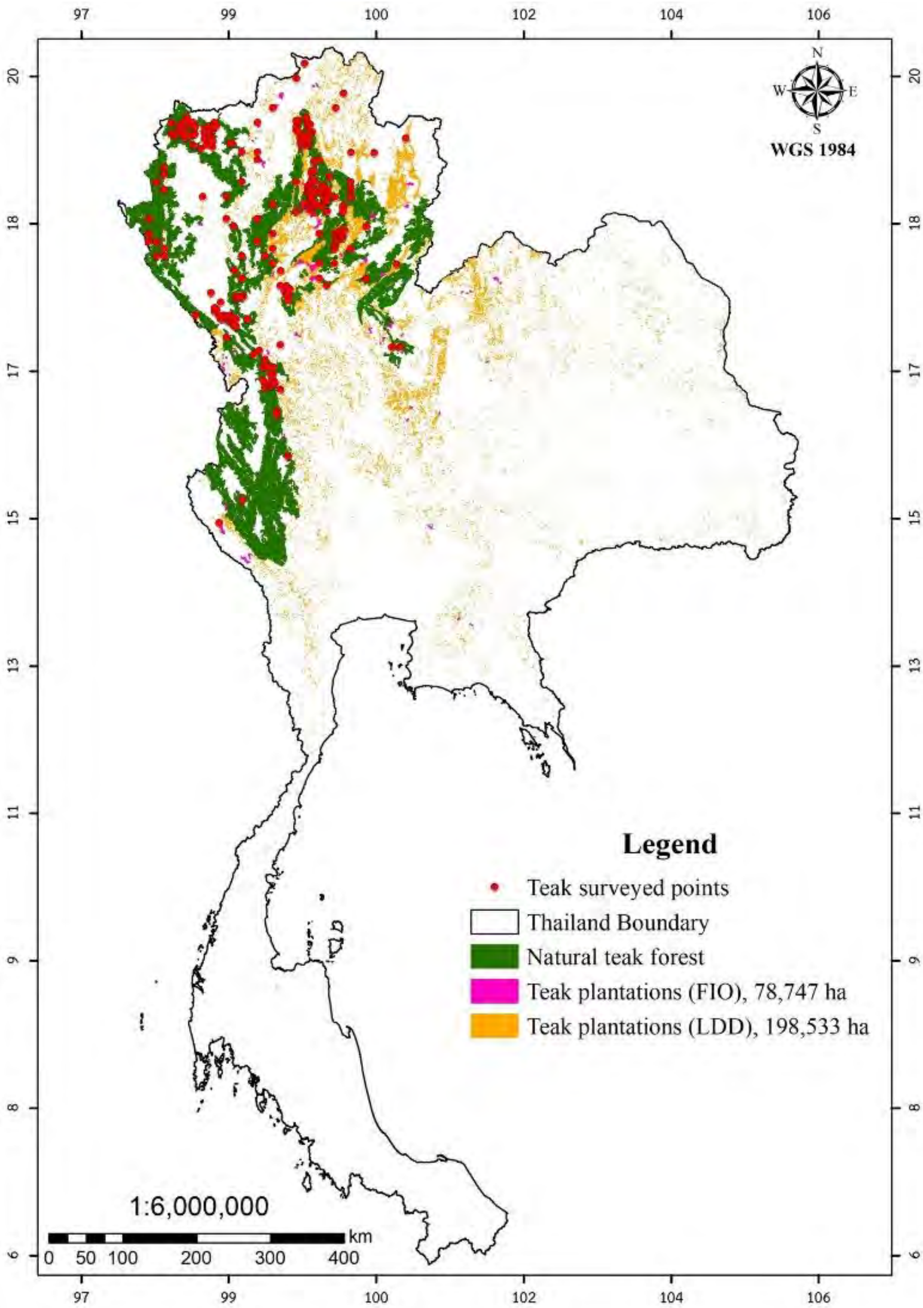


Figure 7-5 Teak distribution in Thailand

Vietnam

Teak was introduced in Vietnam by the French at the turn of the century - largely in parks and along roadsides. Most plantations have been established in the Taungya System as a mixture of food crops (rice, maize, green bean, soya) (Forest Science Sub-Institute of Southern Vietnam, 1998). The first trials were established in the North and South of Vietnam in 1930. Teak planting was carried out widely during 1975-1990 bringing the total area of teak plantations up to 4,700 ha (Photo 7-6). Subsequently some of these were harvested and the total plantation area reported in 2019 by Dong & Ha (2019) was 3,300 ha spread over Northwest, Central highland and Southeast Vietnam. Most recent survey on teak plantations in Vietnam has been carried out by counting the number of trees instead of measuring the area and the survey results in Thanh Hoa and Son La Districts were 15,480 trees (Figure 7-6**).**

Photo 7-6 A 70- years old teak plantation in Dak Lak Province, Vietnam

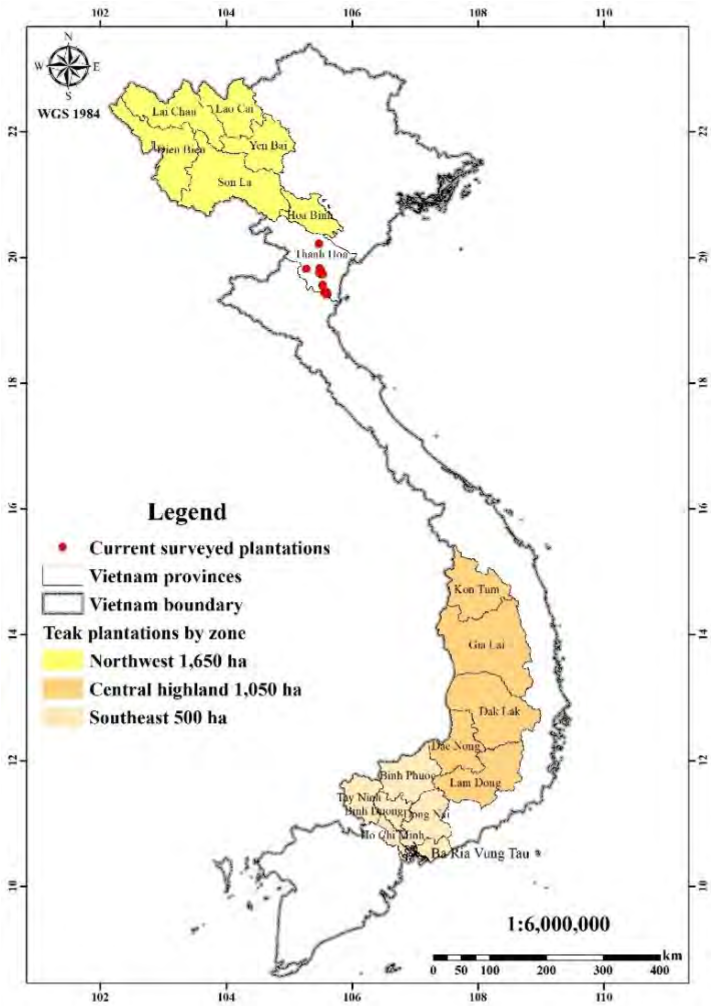


Figure 7-6 Teak distribution in Vietnam by zone

Implications

The results of this study show the distribution pattern of teak in the Greater Mekong Subregion (GMS). The natural forest area has decreased continuously over the past which indicates decrease of the genetic resource base of teak. Many countries have already taken different measures to protect the area, but illegal felling is still prevalent. Teak wood supply can be increased by establishing more plantations in all GMS countries as is already being done but of the diverse and good genetic materials would become scarce in the future if this trend of decline of natural forests continues. It is important to establish several teak seed production areas in the region with exchange of good quality genetic materials between GMS countries and promote tree improvement programs to support good quality teak plantation.

Conclusions

The status of natural teak forests in the Greater Mekong Sub-region, except Myanmar, has been secured by the ban on harvesting in natural forests. Even though latest update of data from Myanmar are lacking, we believe that the largest natural teak forest area is in Myanmar. In Lao PDR, the only natural teak forest left is in the Northwest with an area of 1,100 ha. In Thailand, the natural teak forests are distributed in the North and the West with an area of 1.3 million ha. The area under teak plantations has increased in all the GMS countries and the current status of teak plantations in Myanmar, Thailand, Lao PDR, Cambodia and Vietnam is about 411700, 277300, 29000, 6460, and 3300 hectares respectively.

References

Becker, S. A. (2012). *Largest teak nursery in Cambodia | Phnom Penh Post*. https://www.phnompenhpost.com/post-plus/largest-teak-nursery-cambodia (accessed 12 January 2022).

Dong, T. L. & Ha, D. H. (2019). *Teak Plantation in Vietnam*. https://teaknet.org/download/ITTO Project 2019/Regional Workshop Myanmar/Vietnam.pdf. (accessed 12 January 2022).

Feuerborn. (2018). *Teak Forest, Hiking Trail, Ban Nong Heo Village, Luang Prabang District*, Laos. flickr.com/photos/travfotos/26967373277/in/photostream (accessed 12 January 2022).

FIO (Forest Industry Organization) .(2021). *Economic Tree* Plantation *boundary of Forest Industry Organization*. Government Data Catalog : GD Catalog. https://gdcatalog.go.th/en/dataset/gdpublish-dataset-11_06 (accessed 12 January 2022).

Forest Department. (2020). *Forestry in Myanmar 2020*. Forest Department, Bangkok, Thailand.

Forest Science Sub-Institute of Southern Vietnam. (1998). The management and prospects of teak in Vietnam. *Teak for the Future*. https://innoteak.vn/the-management-and-prospects-of-teak-in-vietnam-difficulties/ (accessed 30 March 2022).

Forestry Administration. (2008). *Kingdom of Cambodia Country Paper on Forestry Outlook 2020*. Phnom Pehn, Cambodia.

Global Forestry Services, Forestry Administration of Cambodia & EU FLEGT Facility. (2014). *Understanding timber flows and control in Cambodia in the context of FLEGT*. Phnom Pehn, cambodia.

Graudal, L. & Moestrup, S. (2017). The genetic variation in natural and planted teak forests: characterisation, use and conservation for the future. In *Global Teak Study (Vol. 36)* (eds. W. Kollert. & M. Kleine), pp. 19–29. IUFRO World Series Volume 36, Vienna, Austria.

Graudal, L., Kjær, E. & Suangtho, V. (1999). Conservation of genetic resources of teak (*Tectona grandis*) in Thailand. *DFSC Series of Technical Notes*, 52, 38.

Hansen, O. K., Changtragoon, S., Ponoy, B., Lopez, J., Richard, J. & Kjaer, E. D. (2017). Worldwide translocation of teak-origin of landraces and present genetic base. *Tree Genetics and Genomes*, 13(4). https://doi.org/10.1007/s11295-017-1170-8

Kaosa-ard, a. (1981). Teak its natural distribution and related factors. *Nat His Bull Siam Soc*, 25, 55–74.

Khaing, N., Min Oo, M., Tun, N. T., Lwin, O. & Minn, Y. (2017). CHAPTER 4. Natural Teak Forests – Silviculture and Stand Management. In: *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources* (eds. Kollert, W. & Kleine, M.), pp. 39–48. IUFRO World Series Volume 36. Vienna.

Kollert, W. & Walotek, P. (2015). Global teak trade in the aftermath of Myanmar's log export ban. *Planted Forests and Trees Working Paper*, 49(49), 20.

Kollert, W. & Walotek, P.J. (2017). Economics, World Teak Resources, Production, Markets and Trade, Chapter 7 Economics, Production, Markets and Trade. In*: The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources* (eds. Kollert, W. & Kleine, M.), pp.83-89. IUFRO World Series Vol 36, Vienna.

Kollert, W., & Cherubini, L. (2012). *Teak resources and market assessment 2010* (Vol. 3, Issue January). FAO Planted Forests and Trees Working Paper FP/47/E.

Land use analysis group. (2021). *Land use status report 2020*. Division of Land use Planning and Policy, Land Development Department, Bangkok, Thailand.

Midgley, S., Mounlamai, K., Flanagan, A. & Phengsopha, K. (2015). *Global Markets for Plantation Teak; Implications for Growers in Lao PDR*. Australian Centre for Internaltional Agricultural Research. Canberra., 74.

Midgley, S., Somaiya, R. T., Stevens, P. R., Brown, A., Kien, N. D. & Laity, R. (2015). Planted Teak: Global Production and Markets, with reference to Solomon Islands. *Australian Centre for International Agricultural Research (ACIAR)*, 92.

Pandey, D. & Brown, C. (2000). Teak: a global overview. An overview of global teak resources and issues affecting their future outlook . *Unasylva,* 51(201), 3–13.

Smith, A. H., Ling, S., Barney, K. & Kanowski, P. (2018). *Advancing enhanced wood manufacturing industries in Lao PDR and Australia Value Chain Assessment : Interim Summary Report - Teak plantations in Northern Lao PDR*. Australian Centre for International Agricultural Research, Australian Capital Territory, Australia.

Sumantakul, V. & Sangkul, S. (1998). Teak resources in Thailand. *Teak for the Future*. https://www.fao.org/3/AC773E/ac773e0h.htm

Tanaka, N., Hamazaki, T. & Vacharangkura, T. (1998). Distribution, growth and site requirements of teak. *Japan Agricultural Research Quarterly,* 32(1), 65–77.

Trisurat, Y., Eiadthong, W., Khunrattanasiri, W., Saengnin, S., Chitechote, A. & Maneerat, S. (2020). Systematic forest inventory plots and their contribution to plant distribution and climate change impact studies in Thailand. *Ecological Research,* 35(5), 724–732.

Chapter 8: Climate Change Impact on Natural Teak Forests in the Greater Mekong Sub-region

Yongyut Trisurat, Sapol Boonsermsuk, Vongvilay Vongkhamsao and Zar Chi Hliang

Abstract

This chapter reviews climate change impacts of native teak and seeks to predict the future geographical distribution of native teak in the Greater Mekong Sub-region as influenced by the climate change. Maximum Entropy (MaxEnt) model was employed to generate present and predicted species range in 2050 under the CMIP6 scenarios. A total number of 383 georeferenced occurrences of teak from various sources were used to model its distribution under the baseline and the four CMIP6 scenarios: SSP1-26, SSP2-45, SSP3-37, and SSP5-85. Key predictor variables were evapotranspiration, tree density, aridity index, elevation, and latitude. Model results predict teak's current natural ranges would either gain or lose suitable habitats of 10% of the existing ranges by 2050. Some forest patches in western Lao PDR and southern Myanmar are likely to disappear and its future climate suitability would shift toward semievergreen forests in northern Myanmar. The remaining suitable habitats at present cover about 19 million ha or two-thirds of the area estimated in 2010. About 40% of the remaining teak occurrence is inside protected areas in Thailand while less than 5% are under strict protection by Myanmar and Lao PDR.

Introduction

Teak (*Tectona grandis*) is one of the most valuable tropical hardwood species in the world due to its captivating wood quality and aesthetics, which finds application in various high-quality products. In addition, its properties like attractive grain and color, medium weight and dimensional stability, easy processing and resilience to different biotic and abiotic factors (climate and soil) make it versatile (Kaosa-ard, 1991), thus it can be used for a wide variety of indoor and outdoor purposes.

Teak is a deciduous tree species, which occurs both in mixed deciduous forests as well as evergreen and semi evergreen forests, but it does not appear as single-species forests as monocultures (Kollert & Cherubini, 2012). Natural teak forests occur within a latitudinal range of 10° to 25°N (Gyi & Tint, 1995) in South and Southeast Asia, especially India, Myanmar, Thailand and Lao PDR (Kollert & Cherubini, 2012). Teak is able to develop under a wide range of annual rainfall: from (600 mm to 5,000) mm, (Mascarenhas et al., 1987; Kaosa-ard, 1991). The tolerance range of mean temperatures lies between 13°C to 43°C, but the optimal temperature ranges from 25°C to 35°C. Teak grows best in light exposed areas and in hilly areas below 900 meters (Pandey & Brown, 2000). In addition, it shows better performances on nutrient rich, deep well drained, sandy-loamy to clay-loamy soils (Kaosa-ard, 1991) although it is also found in nutrient poor acidic soils.

Besides natural teak forests, teak plantations are spread worldwide to partially accommodate the constant demand for teak wood. The establishment of teak plantations has a long tradition across continents and countries. The first teak plantations were established in Java and Muna, Indonesia in the seventh century (Gyi & Tint, 1995). Currently, teak plantations are found worldwide under varied climatic – edaphic conditions, e.g. Caribbean Islands from 1880, (Deval et al., 2003) Central and South America, West Africa, and other Southeast Asian countries such as Vietnam and Philippines (Orwa et al., 2009). About 83 % of the global teak plantation area is located in Tropical Asia, followed by Tropical Africa (11 %) and 6% in Tropical America and less than 1% in Oceania (Kollert & Walotek, 2017).

In this chapter, we assess the potential impacts of climate change on native and non-native teak, in particular in the Greater Mekong Sub-region (GMS). The observed and predicted impacts include response of physiological constraints, change in distribution, and change in ecosystem process and services. In addition, the current efforts on protection measures are included.

Drivers of Impacts on Teak

Non-climate factors

Forest cover in the GMS forests have declined dramatically over the past few decades due to a range of factors. These include rapid economic growth, the conversion of forests to cash crops and plantations, unsustainable logging, as well as infrastructure development. Total forest cover for GMS (excluding Yunnan) has declined from 99.0 million ha (49% of the GMS area) in 1990, to 82.8 million ha (43%) in 2020 or annually (FAO, 2020). All countries except Viet Nam and China have reported falling forest cover, with Cambodia and Myanmar reporting the highest rates of deforestation (-1.17% annually).

Likewise, natural teak forests diminish constantly due to unsustainable logging and encroachment for agriculture (Kollert & Cherubini, 2012). The highest loss of natural forest area during 1976-2010 was found in India with 2.1 million ha, followed by Myanmar with 1.1 million ha. The reduction rate is likely to have changed as a result of the logging ban imposed in India, Lao PDR, Thailand and Myanmar, and the governments allowed only a limited sustainable harvest from natural forests (Roshetko et al., 2009). The total global area of natural teak forests in 2010 was estimated to account for 29 million ha. Nearly half of these forests are located in Myanmar, while teak forests in Thailand are estimated at 8.7 million ha.

Climate factors

In addition to human interference, climate change and extreme events have become a threat to tropical forests, including teak forests (Corlett & Lafrankie, 1998; Trisurat et al., 2009; Patasaraiya et al., 2018). Recent studies indicate that the Indian subcontinent could be subjected to an average of over 4°C rise in temperature by 2085 for SRES A2 scenario (Alexander et al., 2006). Besides, the climatic conditions in the Lower Mekong Basin (LMB) (Myanmar, Thailand, Lao PDR, Cambodia and Vietnam) are also affected by El Nin˜o– Southern Oscillation (or ENSO events) on an approximately 10-year cycle (Rasanent et al., 2016). The downscaled climate data derived from SimCLIM indicated that annual rainfall in the LMB is expected to increase from 1697 mm at the baseline to 1,831 mm in 2030, and to 1,968 mm in 2060 under the wetter overall general circulation model (GCM) forecast. The maximum increment of 344 mm, or 20% from the baseline, is predicted in Vietnam in 2060. In contrast, substantial loss of annual rainfall is expected in northeast Thailand in 2030 under the combined drier condition and medium emissions (Representative Concentration Pathways - RCP 4.5), and in 2060 under the drier condition and high emissions (RCP 8.5). Low emissions (RCP 2.6) would also increase temperature about 0.4 °C across the LMB. Rising temperatures (by 1.5 and 3 °C) are expected for the medium emissions (RCP 4.5) and medium climate sensitivity, and for high emissions (RCP 8.5) and high climate sensitivity, respectively (MRC, 2011).

The sixth phase of the Coupled Model Intercomparison Project (CMIP6), which combined the scenarios of two pathways, a Shared Socioeconomic Pathway (SSP) and an RCP was recently published in 2019 (Durack, 2020). The future climate in 2050 under the SSP1-26, SSP2-45, SSP3-70 and

SSP5-85 scenarios generated by CMIP6 downloaded from WorldClim ver. 2.1 (https://www.worldclim.org/data/cmip6/cmip6climate.html) predicted that annual mean temperature will increase approximately 2.3, 2.4. 3.1, and 3.5 °C from the baseline (Annexes 1, 2), respectively. In contrast, the temperature in the coolest quarter will substantially decline. Precipitation in dry months (driest and warmest quarters) will decrease approximately 36, 35, 45, 65 mm, respectively (Annex 3). These phenomena imply more extreme climatic conditions by 2050.

Climate Change Impacts on Physiology and Ecological Processes

Climate change poses a severe threat to the forest ecosystems by impacting its productivity, species composition and forest biodiversity at all levels. Teak is a tropical tree species which requires alternating rainy and dry seasons to produce high-quality wood. Species traits have also been used to estimate the potential climate change impacts. Among all proxy archives, tree rings are a highly promising indicator of ecological and environmental processes because they are highly sensitive to climatic variation. Muangsong et al. (2020) revealed that the tree-ring inter- and intra- annual stable oxygen isotope ratios (δ18 O) of 146-year-old teak in northern Thailand, spanning between AD 1871 and 2016, are modulated not only by the local rainfall amount, but also by large-scale convection, which varies between different seasons and over time.

Similar studies were conducted by using dendrochronological techniques across the region. D'Arrigo et al. (2011) measured ring width chronology of teak spanning from 1613–2009 at the Maingtha forest reserve north of Mandalay, Myanmar. The research result indicated that teak growth is positively correlated with rainfall and drought variability during and prior to the May–September monsoon season, and the El Niño-Southern Oscillation (ENSO). The teak ring width value following the so-called 1997–98 El Niño of the century, which was one of the most severe droughts in the past ~300 years history in Myanmar. This evidence is consistent with tree-ring records in Thailand.

Lumyai & Duangsathaporn (2018) monitored ring width of 52 teak trees extended back 127 years (1886-2012) at Umphang Wildlife Sanctuary in Tak Province. The ring-width index showed a positive correlation with total rainfall during wet months (March and June). The ring width increased during a wet period occurred in 1887-1895 and gradually decreased to a stable pattern in 1927-1945 with a further decline during the dry periods occurring in 1896-1926, 1946-1955, 1965-1981 and 1982-2012.

For India, monsoon rains usually occur during June–September, and post monsoon during October–November. Monthly rainfalls show an increasing trend during monsoon months, and pronounced decreasing trend in post monsoon rainfall towards inland. However, this pattern is different from the coast primarily due to moisture availability from sea. Sengupta et al. (2018) revealed that ring width data show moderately positive response to monsoon rainfall and negative response to summer temperature due to moisture deficit in hot summer. The increasing moisture stresses during months of the early growing season is crucial for determining the growth of teak trees (Upadhyay et al., 2021). Nevertheless, intense precipitation in monsoon affects ring growth pattern at coastal location.

Ngoma et al. (2019) studied the effects of changes in temperature, rainfall, atmospheric carbon dioxide (CO_2) concentration, solar radiation, and number of wet days on net primary productivity (NPP) of the Zambian Zambezi teak forests along a rainfall gradient. The dynamic vegetation model, LPJ-GUESS, was employed to simulate the growth of

Zambian forests along the annual rainfall gradient of between 700 and more than 1,000 mm. The projected NPPs by the end of the 21st century (2070–2099) under RCP4.5 and RCP8.5 scenarios were compared with the baseline (1960-1989). The model results predicted that the future NPP would increase by 0.69-1.77 % at the wettest site, and by 0.10-0.44 % at the intermediate wet site under RCP8.5 and RCP4.5 respectively, by the end of the 21st century. However, at the drier site, NPP would respectively decrease by 0.01 % and 0.04 % under RCP8.5 and RCP4.5, which were resulted from the reduced rainfall coupled with increasing temperature. This study implies that precipitation, especially in dry months, is a limiting factor in the drier sites. The result is different from the area where rainfall is sufficient and quite stable (>1,00 mm per year). Patasaraiya et al. (2018) used time series data provided by Landsat MODIS and NDVI (Normalized difference vegetation indices) to detect changes of Teak and Sal Forest of Satpura tiger reserve in central India as the result of climatic variation between the period 2017 and 1990. The study found an increasing trend in the average annual NDVI of Teak and Sal forests as the result of increasing annual mean temperature. However, Sal is more sensitive to mean temperature, whereas Teak is more sensitive to change in maximum temperature.

Changes in light intensity causes effect on the rate of photosynthesis. It has been reported that teak requires a light intensity between 50-75% of full sunlight for optimum growth and development (Nwoboshi, 1972) and between 40-80% for optimum growth of teak seedlings (Moonchun et al., 2017). As climate change has contributed to tree mortality and a reduction in plant community, as well as a sudden light change due to a gap opening. Recent study indicated that the teak seedlings do not go well either under shade, or in full sunlight, but it performs well under moderate shade at least 10% sunlight (Leksungnoen et al., 2021).

The laboratory analyzes showed that moderate and severe drought stress reduces the rate of photosynthesis, transpiration, stomatal conductance and leaf relative water content of teak seedlings (Galeano et al., 2019). An increase in free proline (amino acid) levels and intrinsic water use efficiency was found when compared to the control treatment. Furthermore, biochemical adjustments in leaves and genetic changes in roots were observed and become a limiting factor for teak seedlings' growth.

Projected Climate Change Impacts on Teak Distribution

The 5th Assessment Report (WGII AR5 SPM) stated that many biomes, ecosystems and species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (IPCC, 21 2014). Deb et al. (2017) reported that changes in annual precipitation, precipitation seasonality and annual mean actual evapotranspiration may result in shifts in the distributions of native teak and teak plantations across tropical Asia. The generalized (ecoregion-based) suitable areas predicted in 2050 are dramatically different with 2070 extreme scenarios. Substantial losses of suitable climate were predicted for deciduous teak forests of Myanmar, Laos and Thailand under RCP6.0 and RCP8.5 scenarios (Figure 8-1). In contrast, some ecoregions in central and northern India are likely to become suitable for teak in future. The finer resolution modeling results based on the regional climate model of the Hadley Center (HadRM3) projected mixed patterns of gain and loss in suitable areas. It showed that about 30% of teak grids in India will become vulnerable to climate change under both A2 and B2 SRES scenarios (Gopalakrishnan et al., 2010). For teak plantations, Pirovani et al. (2018) indicated that the reduction in monthly rainfall and an increase in average air temperature by 2.1 °C reduce suitable cultivation area of teak in Brazil. This is consistent with the model results conducted in teak plantations in north-eastern Bangladesh (Deb et al., 2017).

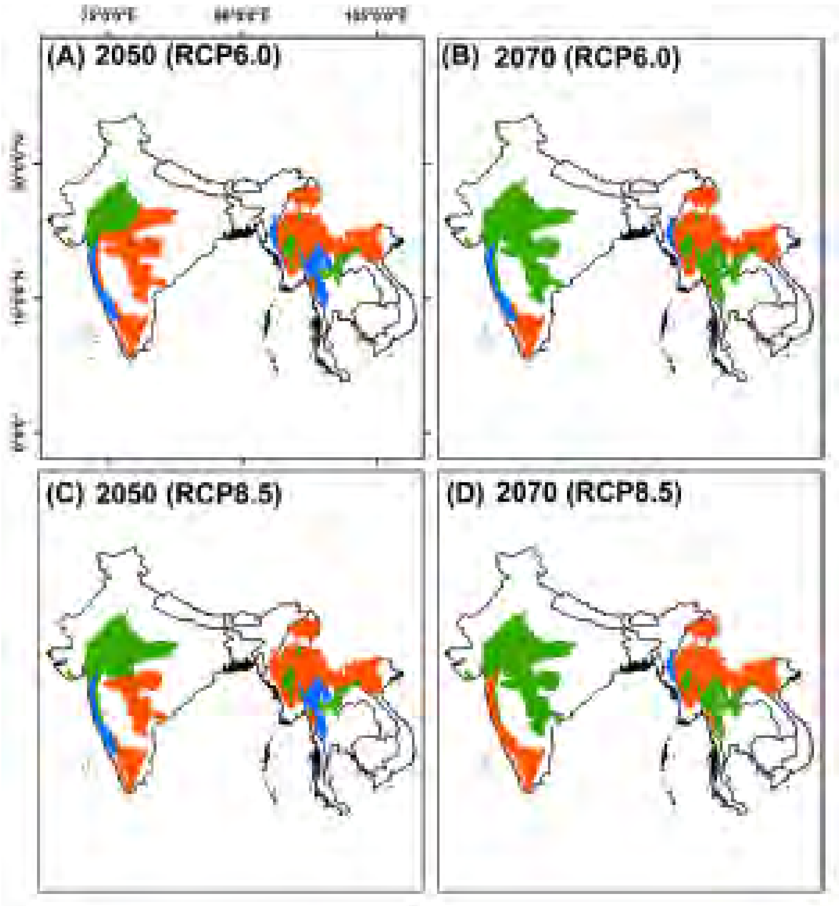


Figure 8-1 Predicted suitable ecoregions of natural teak and changes in climate space by 2050 and 2070 under RCP6.0 and RCP8.5 scenarios

Notes: Blue – remaining habitat; Red – loss of climate space; Green – Gain of suitable area

Source: Deb et al. (2017)

Modeling Teak Distribution and Climate Change Impacts in GMS

As mentioned in the introduction section, this chapter emphasized on the potential impacts of climate change on native teak forests situated in Myanmar, Lao PDR, and Thailand. These three countries account for approximately 1.4 million km^2 or 61% of the total land area in the GMS. Vietnam and Cambodia do not have natural teak forests, but have teak plantations approximately 50,000 – 60,000 ha.

With the collective efforts of the project staff from the participating countries, the total number of teak occurrences of 1,579 records were gathered from a variety of sources, largely from ITTO/Thailand's systematical forest inventory plots (854 records or 54% of the total records; Trisurat et al. (2020). After filtering the locality data to avoid spatially auto-correlated occurrence, the occurrence points were reduced to 383 records (Figure 8-2, Figure 8-3). Of this number, 221 records were located in Thailand, followed by Myanmar (133 records) and Lao PDR (29 records).

The occurrence data were correlated with environmental variables directly or indirectly affect the native teak distribution at an environmental heterogenous scale using the maximum entropy method (MaxEnt) (Phillips et al., 2006). The MaxEnt was chosen because it works well with only-present data of environmental variables that were developed. Physical variables include altitude (from Shuttle Radar Topography Mission -SRTM), and slope. Soil characteristics were obtained from FAO/IIASA/ISRIC/ISSCAS/JRC (2012) and ISRIC-World Soil Information version 2.0. Other variables include the annual Aridity Index (AI) (Trabucco & Zomer, 2019), and reference evapotranspiration (ETo) (Subburayan et al., 2011). In addition, mean tree density per km^2 was also downloaded from Crowther et al. (2015) version 2. Ten uncorrelated bioclimatic variables from WorldClim ver. 2.1(https://www.worldclim.org/data/cmip6/cmip6climate.html) based on averages of 1970-2000 at 30-second resolution (approximately 1 km) were used as the baseline (Table 8-1) to determine the current distribution. For the projected distribution in 2050, we treated other variables stable and changed only climatic variables to the same bioclimatic variables projected by four CMIP6 SSPs: 1-26, 2-45, 3-70 and 5-85 processed from (CanESM5 and GFDL-ESM4). All environmental variables were resampled to 30 seconds or 1 km resolution, which is appropriate for analysis at the national level.

The model results revealed that key predictor variables for natural teak distribution were ETo (23.56%), followed by tree density (18.54%), AI (11.46%), elevation (10.4%), and latitude (8.12%) (Table 8-1). The results also highlight that climate seasonality (temperature of wettest quarter [B8] and warmest quarter [B10], precipitation of wettest [B18] and coolest quarter [B19]) rather than the mean annual climate (annual mean temperature [B1] and annual precipitation [B12]) is more important for the distribution of natural teak.

Table 8-1 Variables and their contributions in the MaxEnt models for teak (*Tectona grandis*)

Variable	Description	Contribution to the MaxEnt models (%)			
		%	Min	Max	SD
BIO1	Annual mean temperature	0.00	0.00	0.00	0.00
BIO8	Mean temperature of wettest quarter	4.64	3.00	6.40	1.48
BIO9	Mean temperature of driest quarter	0.12	0.00	0.30	0.10
BIO10	Mean temperature of warmest quarter	2.14	0.10	4.30	1.58
BIO11	Mean temperature of coldest quarter	0.36	0.30	0.50	0.08
BIO12	Annual precipitation	0.60	0.00	1.60	0.70
BIO16	Precipitation of wettest quarter	0.98	0.20	1.90	0.68
BIO17	Precipitation of driest quarter	0.60	0.00	1.40	0.58
BIO18	Precipitation of warmest quarter	3.82	2.60	6.00	1.25
BIO19	Precipitation of coldest quarter	2.38	1.70	2.90	0.52
AI	Aridity index	11.46	9.10	15.80	2.53
ETo	Reference evapotranspiration	23.56	19.40	27.20	2.53
DEM	Elevation	10.04	8.60	12.40	1.35
SLOPE	Slope	3.36	0.20	6.30	2.45
LAT	Latitude	8.12	6.00	10.20	1.47
SOIL	FAO soil unit	5.24	3.80	8.60	1.79
BLDTICM	Soil depth	2.78	1.60	4.10	0.90

Variable	Description	Contribution to the MaxEnt models (%)			
		%	Min	Max	SD
BLDFIE	Soil bulk density	1.06	0.30	1.70	0.63
TREE_DENS	Tree density per km2	18.54	16.40	20.80	1.68

The predicted distribution of native teak at present covered an area of 38.10 million ha or 25.91% of the study area. Of this figure, 22.02 million ha (49% of the total suitable area) was predicted in Myanmar, 16.43 million ha (38%) in Thailand, and 5.68 million ha (13%) in Lao PDR (Table 8-2). Suitable areas are mainly clustered between latitudes 17° to 22°N across the borders of the three countries (Figure 8-2, Figure 8-3). Northern Myanmar dominated by semi-evergreen forests shows less suitability, and teak does not grow to a great size and usually scattered individuals or in small groups (Gyi & Tint, 1995) compared to mixed deciduous forests. Using the existing land use map from Copernicus Global Land Service (Buchhorn et al., 2019), it was predicted that the remaining teak areas in 2019 covered 18.90 million ha or 13.29% of the study area, which was substantially different with the estimation by Kollert & Cherubini (2012). About 43% of the total remaining teak occurrence was predicted in Myanmar, whereas 41% and 16% are located in Thailand and Lao PDR, respectively. Substantial loss has been detected in Myanmar due to unsustainable logging (Forest Department, 2020; FAO, 2020). Less reduction was estimated Thailand. This is due to forest cover in Thailand is quite stable after 2000 because of the increased efforts of forest protection and expansion of protected areas.

Table 8-2 Estimated extend of occurrence, gain, and loss in the suitable range.

Scenario	Suitable area		Remain	Gain	Loss	Remaining suit area	
	(mill ha)	%	(mill ha)	(mill ha)	(mill ha)	(mill ha)	%
Baseline	38.10	25.91				18.90	13.29
SSP1-26	39.08	26.61	35.08	4.04	2.99	19.78	13.98
SSP2-45	37.18	25.28	33.82	3.36	4.24	18.53	13.09
SSP3-70	38.02	25.84	34.58	3.44	3.49	19.25	13.59
SSP5-85	37.02	25.22	33.52	3.57	4.55	18.50	13.01

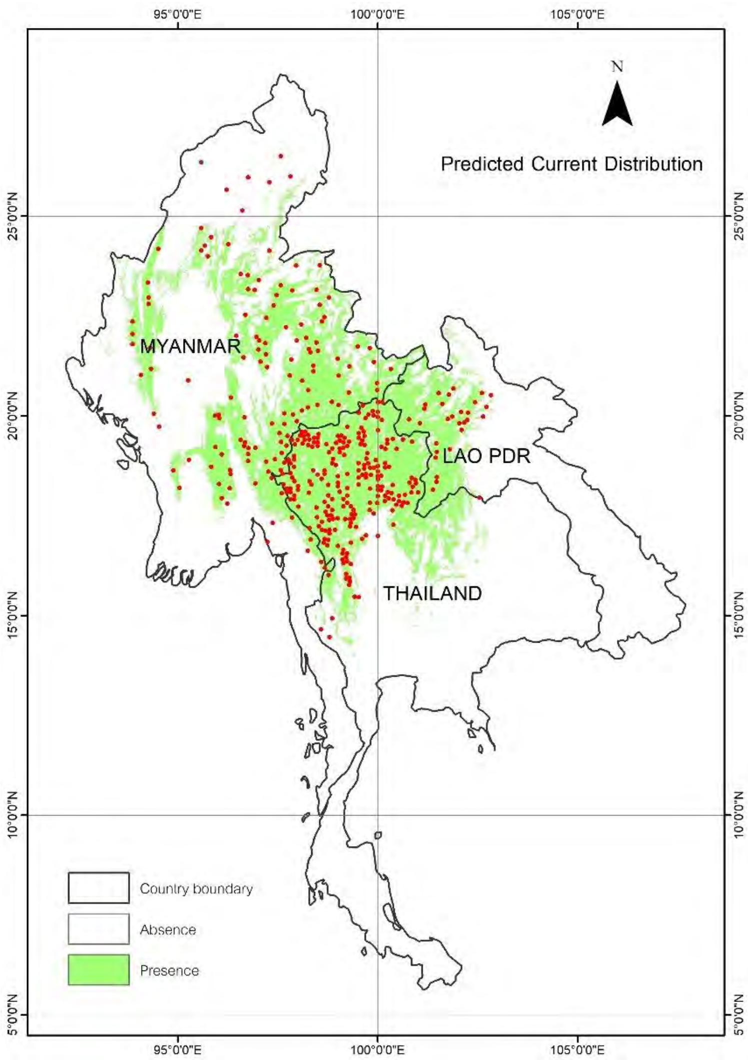


Figure 8-2 Potential suitable habitats at baseline

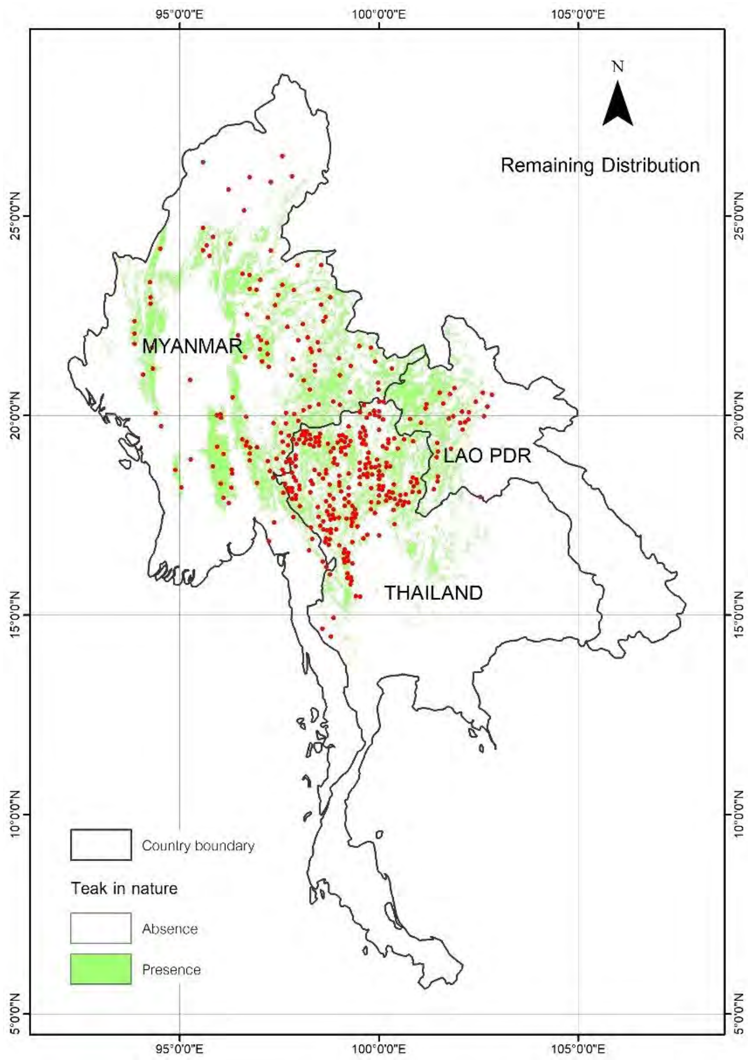


Figure 8-3 Remaining suitable habitats at baseline (Masked by land use map)

The predicted distribution areas under the four CMIP6 scenarios show that the suitability of native teak will be stable at 20% of the total study area, except the CMIP6 SSP12-6 and SPP5-85 scenarios. However, its current natural ranges would either gain or lose suitable habitats of 10% of the existing natural ranges by 2050 (Table 8-2, Figure 8-4). Some forest patches in western Lao PDR and southern Myanmar are likely to lose climate suitability, whereas some patches situated in semi-evergreen forests in northern Myanmar are likely to become suitable in the future.

The Protected Planet (https://www.protectedplanet.net/en) indicates that the extent of protected areas in Myanmar, Thailand, and Lao PDR cover about 3.43, 3.60 and 11.03 million ha or 5, 15, and 21% of the country land area, respectively. The model results reveal that 0.35 million ha, 0.26 million ha, and 5.36 million ha of suitable areas are found inside protected areas of Myanmar, Lao PDR and Thailand, respectively. These imply that the percentage of protected area contributions are approximately 2, 5 and 40%, respectively.

Conclusion

A total number of 383 georeferenced occurrences of teak from various sources were used to model its distribution under the baseline and the four CMIP6 scenarios: SSP1-26, SSP2-45, SSP3-37, and SSP5-85. The species distribution models show excellent performance to predict the current and future teak distributions.

The key predictor variables for natural teak distribution were annual reference evapotranspiration, followed by tree density, aridity index, elevation, and latitude. Although teak has a wide climatic tolerance range, climate seasonality shows more important than annual precipitation and mean temperature because teak prefers distinct wet and dry climate seasons.

The model results predicted the potentially suitable areas at the baseline and under the four CMIP6 scenarios cover about 38 million ha or 25% of the total study area. The current habitats inside the remaining forest cover encompass about 19 million ha or 13% of the total study area. Great loss is estimated in Myanmar due to unsustainable logging and changing climate patterns. Protected areas in Thailand contribute about 40% of the remaining suitable area of the country, whereas its contribution is less for Myanmar and Lao PDR. Its current natural ranges would either gain or lose suitable habitats of 10% of the existing ranges by 2050. Some forest patches in western Lao PDR and southern Myanmar are likely to disappear and its future climate suitability would shift toward northern Myanmar.

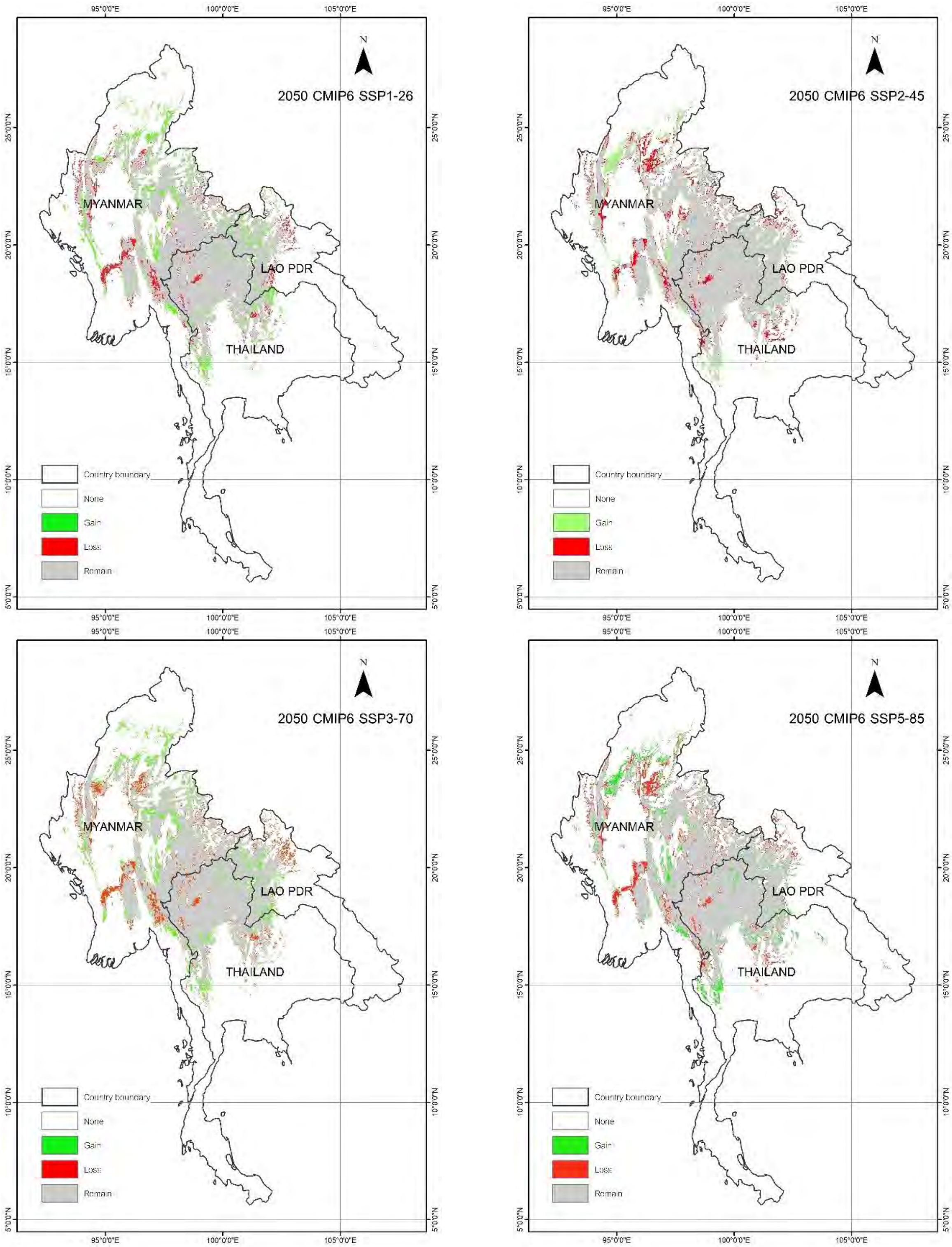


Figure 8-4 Predicted climate change impact on teak distribution by 2050 under CMIP6 scenarios

References

Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G. & Vazquez-Aguirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research: Atmospheres*, *111*(D5).

Arrigo, D., R., Palmer, J., Ummenhofer, C. C., Kyaw, N. N. & Krusic, P. (2011). Three centuries of Myanmar monsoon climate variability inferred from teak tree rings. *Geophysical Research Letters*, 38(24). Mandalay.

Buchhorn, M., Smets, B., Bertels, L., Lesiv, M., Tsendbazar, N.R., Herold, M. & Fritz, S. (2019). Copernicus Global Land Service: Land Cover 100m: collection 2: epoch 2015: Globe (V2.0.2) [Data set]. ESA Living Planet Symposium 2019 (LPS2019), Milan, Italy. Zenodo. https://doi.org/10.5281/zenodo.3243509

Corlett, R. T. & Lafrankie, J. V. (1998). Potential impacts of climate change on tropical Asian forests through an influence on phenology. *Climatic change*, 39(2), 439-453.

Crowther, T. W., Glick, H. B., Covey, K. R., Bettigole, C., Maynard, D. S., Thomas, S. M., & Bradford, M. A. (2015). Mapping tree density at a global scale. *Nature*, *525*(7568), 201-205.

Deb, J. C., Phinn, S., Butt, N. & McAlpine, C. A. (2017). Climatic-induced shifts in the distribution of teak (Tectona grandis) in tropical Asia: implications for forest management and planning. *Environmental management*, 60(3), 422-435.

Devall, M. S., & Parresol, B. R. (2003). A dendrochronological study of teak (*Tectona grandis* L. f., Verbenaceae) In *Puerto Rico. In International Conference of Quality Timber Products of Teak From Sustainable Forest Management*, p.424-434, December 2-3, Peechi, India.

Durack, P J. (2020). *CMIP6_CVs.* v6.2.53.5. Available at: https://github.com/WCRP-CMIP/CMIP6_CVs (accessed: 26 October 2021)

FAO. (2020). *Global Forest Resources Assessment 2020*: Main report, Rome. https://doi.org/10.4060/ca9825en

FAO/IIASA/ISRIC/ISSCAS/JRC. (2012). Harmonized world soil database (version 1.2). FAO, Rome, Italy & IIASA, Laxenburg, Austria.

Forest Department. (2020). *Forestry in Myanmar 2020*. Ministry of Natural Resources and Environmental Conservation, Myanmar.

Galeano, E., Vasconcelos, T. S., Novais de Oliveira, P., & Carrer, H. (2019). Physiological and molecular responses to drought stress in teak (*Tectona grandis* Lf). *PloS one*, 14(9), e0221571.

Gopalakrishnan, R., Jayaraman, M., Swarnim, S. et al. (2010). Impact of climate change at species level: a case study of teak in India. *Mitig Adapt Strateg Glob Change, 16***,**199–209. https://doi.org/10.1007/s11027-010-9258-6

Gyi, U.K.K. & Tint, K. (2015). Management status of natural teak forests. In: *Teak for the Future - Proceedings of the Second Regional Seminar on Teak* (ed. Masakazu Kashio & Kevin White) 29 May - 3 June 1995, Yangon, Myanmar, TEAKNET Secretariat in the Forest Department, Yangon, Myanmar.

IPCC. (2014). Summary for policymakers. In: *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects*. (eds. C.B. Field, V. R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L.Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, AV. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White), pp. 1–32. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on

Climate Change, Cambridge University Press, Cambridge.

Kaosa-ard, A. (1991). Country report on Teak in Thailand, Paper presented at the China/ESCAP/FAO Regional Seminar on Teak, Guangzhou, China.

Kollert, W. & Cherubini, L. (2012). *Teak resources and market assessment*. Planted Forests and Trees Working Paper FP/47/E. Edited by Food and Agriculture Organization of the United Nations, Rome. Available online at http://www.fao.org/3/an537e/an537e00.pdf, checked on 5/3/2021.

Kollert, W. & Walotek, P.J. (2017). Economics, World Teak Resources, Production, Markets and Trade, Chapter 7 Economics, Production, Markets and Trade. In *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources.* (eds. W. Kollert & M. Kleine), pp.83-89. *IUFRO World Series Vol 36* Vienna.

Leksungnoen, N., Uthairatsamee, S., & Andriyas, T. (2021). Adaptability of Siamese Rosewood and Teak Seedlings to Varying Light Conditions. *Environment and Natural Resources Journal (EnNRJ)*, 19(6), 449-458.

Lumyai, P. & Duangsathaporn, K. (2018). Climate reconstruction on the growth of teak in Umphang Wildlife Sanctuary, Thailand. *Environment and Natural Resources Journal*, 16(1), 21-30.

Mascarenhas, A. F., Kendurkar, S. V., Gupta, P. K., Khuspe, S. S., & Agrawal, D. C. (1987). Teak. In *Cell and tissue culture in forestry*, pp. 300-315. Springer, Dordrecht.

Moonchun, S., Leksungnoen, N., Uthairatsamee, S. & Moungsrimuangdee, B. (2017). Effect of light intensity on growth and photosynthesis related variables of forest tree seedlings. *Thai Journal of Forestry 2017,* 36(2),12-23.

MRC. (2011). *Planning atlas of the Lower Mekong River Basin. Basin Development Plan Programme*. Mekong River Commission, Vientiane, Laos.

Muangsong, C., Pumijumnong, N., Cai, B., Buajan, S., Lei, G., Wang, F., & Payomrat, P. (2020). Effect of changes in precipitation amounts and moisture sources on inter-and intra-annual stable oxygen isotope ratios (δ18O) of teak trees from northern Thailand. *Agricultural and Forest Meteorology*, *281*, 107820.

Ngoma, J., Braakhekke, M. C., Kruijt, B., Moors, E., Supit, I., Speer, J. H., & Leemans, R. (2019). Modelling the response of net primary productivity of the Zambezi teak forests to climate change along a rainfall gradient in Zambia. *Biogeosciences*, 16(19), 3853-3867.

Nwoboshi L. (1972). Responses of Teak (*Tectona grandis* L.f.), Idigbo (*Terminalia ivorensis* Achev) and Opepe (*Naclea diderrichii* Mervill) seedlings to various light intensities. *Nigerian Journal of Forestry, 2*(2),48-53.

Orwa, C., Mutua, A., Kindt R , Jamnadass, R. & Anthony, S. (2009). Agroforestree Database:a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp)

Pandey, D. & Brown, C. (2000). Teak: a global overview. An overview of global teak resources and issues affecting their future outlook. *Unasylva, 51*(201), 3–13.

Patasaraiya, M. K., Sinha, B., Bisaria, J., Saran, S., & Jaiswal, R. K. (2018). Assessing impacts of climate change on teak and sal landscape using MODIS time series data. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*.

Phillips, S. J., Anderson, R. P. & Schapire, R. E. (2006). Maximum entropy modeling of species geographical distributions. *Ecological Modelling, 190*, 231-259.

Pirovani, D. B., Pezzopane, J. E. M., Xavier, A. C., Pezzopane, J. R. M., de Jesus Júnior, W. C., Machuca, M. A. H. & dos Santos, A. R. (2018). Climate change impacts on the aptitude area of forest species. *Ecological indicators*, *95*, 405-416.

Rasanent, T. A., Lindgren, V., Guillaume, J. H. A., Buckley, B.M., & Kummu, M. (2016). On the spatial and temporal variability of ENSO precipitation and drought teleconnection in mainland Southeast Asia. *Clim Past, 12*,1889–1905.

Roshetko, J. M. & Manurung, G. E. (2009). Smallholder teak production systems in Gunungkidul, Indonesia. In *Poster presented at the 2nd World Congress of Agroforestry,* Nairobi.

Sengupta, S., Borgaonkar, H., Joy, R. M. & Ram, S. (2018). Monsoon climate response in Indian teak (*Tectona grandis* Lf) along a transect from coast to inland. *Theoretical and Applied Climatology*, *134*(3), 1197-1205.

Subburayan, S., Murugappan, A. & Mohan, S. (2011). Modified Hargreaves equation for estimation of ET0 in a hot and humid location in Tamilnadu State, India. *Int J Eng Sci Technol 3*(1), 592–600

Trabucco, A & Zomer, R. (2019). *Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2*. figshare. Dataset. https://doi.org/10.6084/m9.figshare.7504448.v3

Trisurat, Y. (2018). Planning Thailand's protected areas in response to future land use and climate change. *International Journal of Conservation Science, 9*(4), 805-820.

Trisurat, Y., Alkemade, R. & Arets, E. (2009). Projecting forest tree distributions and adaptation to climate change in northern Thailand. *Journal of Ecology and Natural Environment,* 1(3), 55-63.

Trisurat, Y., Eiadthong, W., Khunrattanasiri, W., saengnil, S., Chitechote, A. & Maneerat, S. (2020). *Systematic forest inventory plots and their contribution to plant distribution in Thailand*. Ecological Research: Data Paper. https://doi.org/10.1111/1440-1703.12105 (doi: 10.1111/1440-1703.12105).

Upadhyay, K. K., Shah, S. K., Roy, A., & Tripathi, S. K. (2021). Dendroclimatology of teak indicates prevailing climatic conditions of tropical moist forests in India. *Ecological Indicators*, 129, 107888.

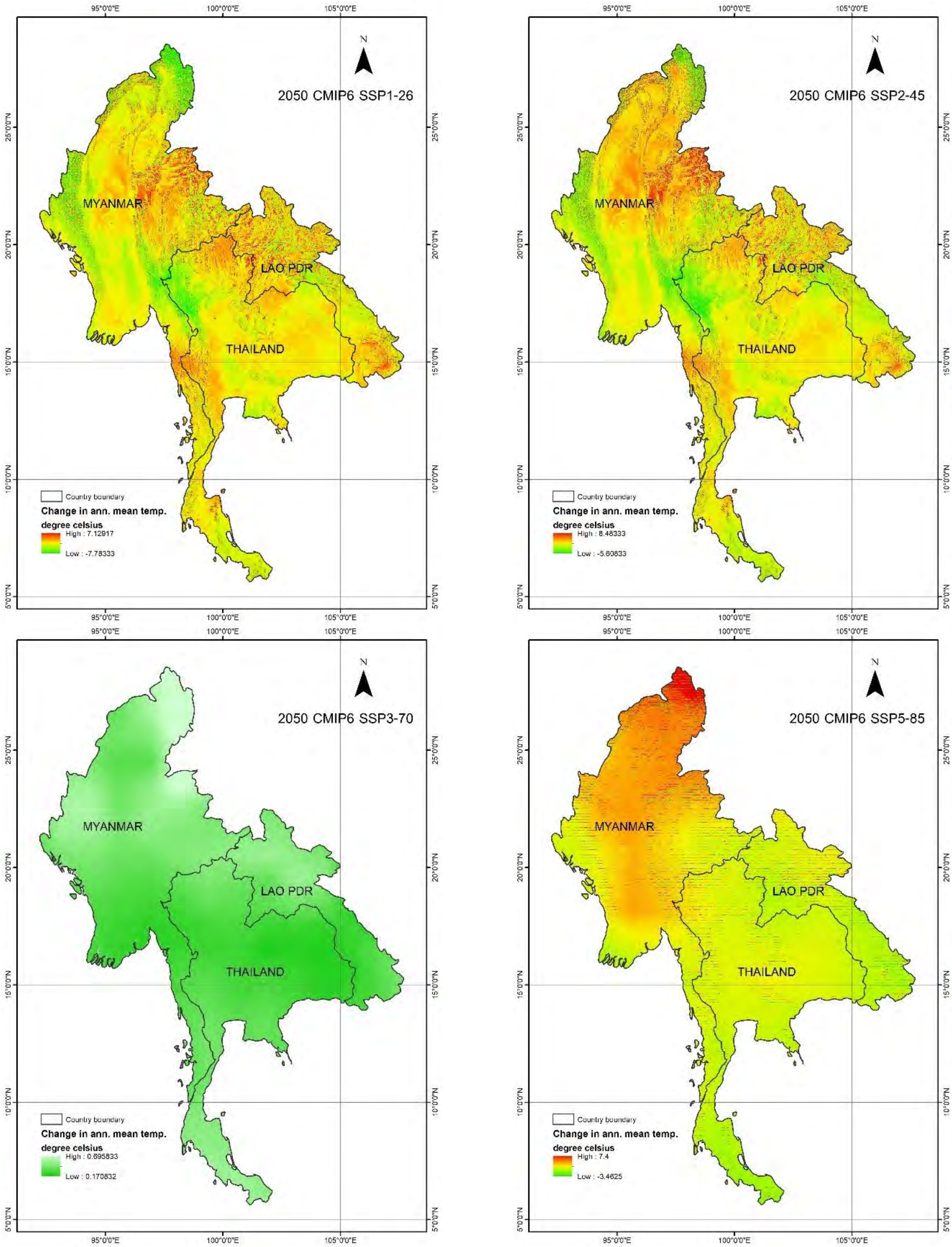
Annex 8-1 Predicted climatic condition under CMIP6 scenarios

Variable	2000				SSP1-26				SSP2-45				SSP3-70				SSP5-85			
	Min	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
BIO1	-4.5	28.9	24.15	3.268	-1.2	29.8	25.4	3.3	-0.7	30.8	26.5	3.2	0	30.1	27.7	3.2	.0	31.5	27.2	3.2
BIO8	1.9	29.7	25.58	2.39	5.9	30.5	26.7	2.3	6.4	5.5	30.9	27.6	2.3	6.4	30.8	27.1	6.1	31.8	28.3	6.1
BIO9	-10	28	21	4.23	-7.2	29.4	22.4	4.2	-6.3	30.3	23.4	4.1	-6.1	30	22.8	4.2	-5.4	30.8	24.1	4.1
BIO10	1.9	31.4	26.81	2.83	5.9	32.6	28.3	2.8	5.5	34.2	29.4	2.8	6.4	32.9	28.6	2.8	9.0	35.3	30.3	2.9
BIO11	-11.1	27.5	20.39	4.25	-7.2	29.4	22.4	4.2	-7.8	29.2	22.7	4.2	-8.8	28.3	21.7	4.3	-5.1	29.7	23.4	4.2
BIO12	581	5722	1792.5	754	646	58.69	1769.2	790.5	677	5963	1880.9	821.4	621	5623	1722.2	749.9	666	5998	1887.6	832.1
BIO16	251	3807	1016.4	545	329	4190	1026.4	584.9	369	4356	1085,9	590.2	317	3748	999.1	540.3	377	4437	1107.2	597.7
BIO17	2	391	37.7	369	3	367	32.9	29.8	3	378	33.9	31.8	3	365	31.7	28.2	3	351	33.6	29.9
BIO18	143	2445	567.7	351.8	114	2391	536,5	388.8	129	2739	539.5	372.5	112	2254	528.3	356.6	111	2892	507.2	383.6
BIO19	4	2958	67.6	135.9	6	3352	75.5	199.1	5	3760	76.6	213.8	4	3593	77.1	221.3	5	3893	77.4	226.9

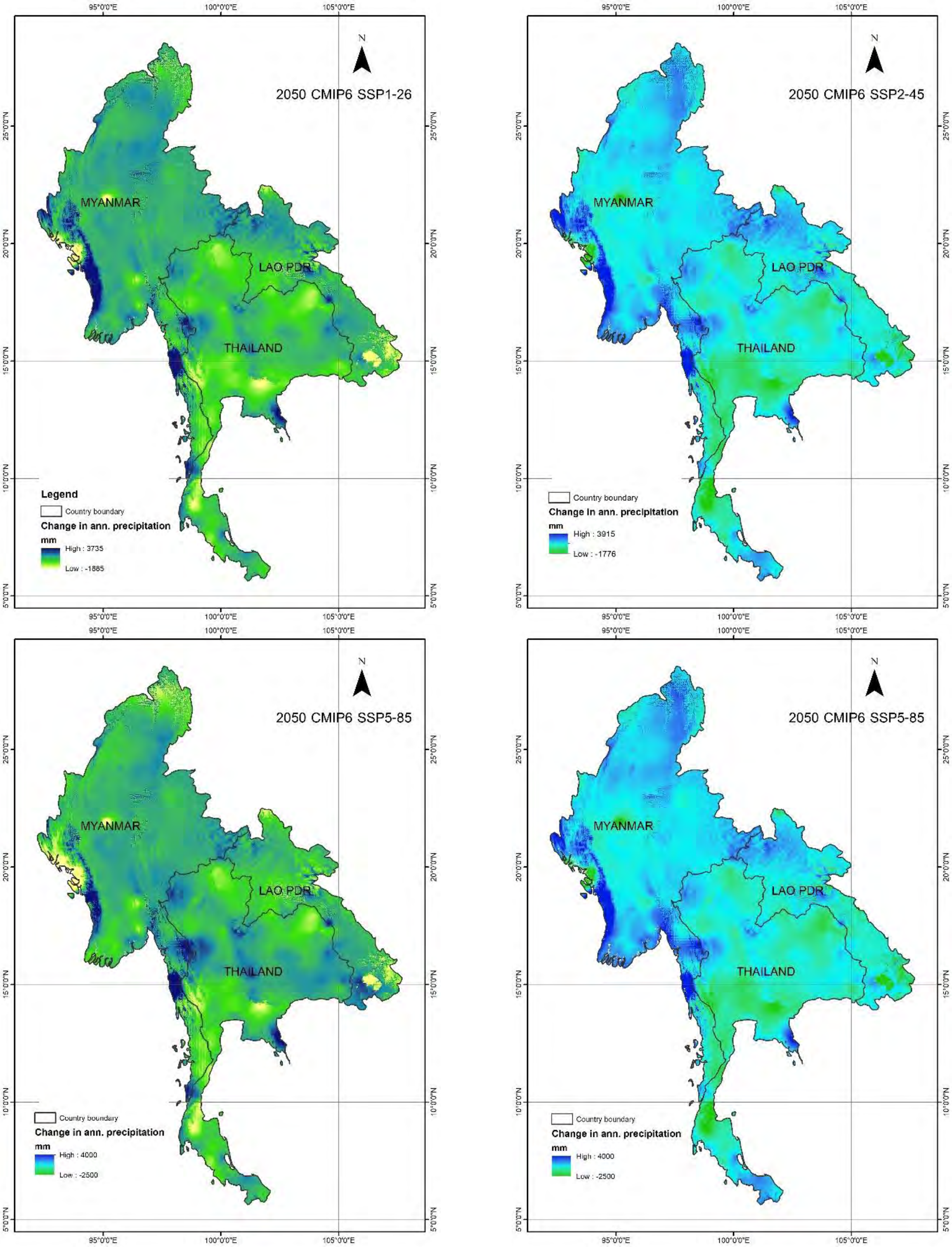
Notes: BIO1 = Annual Mean Temperature; BIO8 = Mean Temperature of Wettest Quarter; BIO9 = Mean Temperature of Driest Quarter; BIO10 = Mean Temperature of Warmest Quarter; BIO11 = Mean Temperature of Coldest Quarter; BIO12 = Annual Precipitation; BIO16 = Precipitation of Wettest Quarter; BIO17 = Precipitation of Driest Quarter; BIO18 = Precipitation of Warmest Quarter; BIO19 = Precipitation of Coldest Quarter

Source: https://www.worldclim.org/data/cmip6/cmip6climate.html

Annex 8-2 Predicted climate change in annual mean temperature by 2050 under CMIP6 scenarios



Annex 8-3 Predicted climate change in annual precipitation by 2050 under CMIP6 scenarios



SECTION III

SILVICULTURAL PRACTICES AND TEAK IMPROVEMENT

Chapter 9: Teak Plus Tree Selection and Its Propagation Techniques Used In Thailand

Chumnun Piananurak

Abstract

Characteristics to selection of Plus trees are dependent on the end use of the wood produced. Since teak fetches highest prices when usable as veneer, marine decking, furniture, etc., its stem form and wood texture are the most important traits for selection. Once plus tree is selected it could be propagated both by seed and vegetative means. Propagation by seeds is the easiest technique used by small farmers and, therefore, there is a need to establish more seed orchards to produce enough high- quality seeds for plantation. Teak can be vegetatively propagated by budding, rooted cutting and tissue culture each of which has both advantages and disadvantages and suitable technique should be used in order to gain the highest benefit. Budding technique by Open-two-flap was used for a long time until Chip-patch technique was developed which lends itself to very fast paced application. Budding is most successful when propagating mature material because budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture. The technique is, therefore, recommended for application in first stage propagation of Plus trees subsequent to which other techniques can be used as needed. It is not advisable to use budded seedlings to directly establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak but is less successful when mature materials are used. In the establishment of clone bank, clonal test, or clonal seed orchards, where a large number of clones but only a few seedlings per clone are involved, budding technique may be used to first rejuvenile mature materials and then undertake rooted cutting of the rejuvenile shoots to produce seedlings. In the case of mass production of elite plants, it is preferable to use tissue culture to produce juvenile stock plants for rooted cutting. When there are enough stock plants, rooted cutting is more useful than tissue culture.

Introduction

Teak is one of the most preferred species for plantation in Thailand creating huge demand for high quality planting stock across the country. Planting stock across the country is produced by three agencies, namely, farmers, Forest Industrial Organization (FIO), and the Royal Forest Department (RFD). A large part is produced by the Reforestation Promotion Office under the RFD producing almost 4 million seedlings per year. The second agency is small farmers in Lampang, Khonkan, Uttaradit and Phitsanulok provinces totaling more than 2 million seedlings. The last agency is the FIO whose central nursery for teak seedling production is located at Mae Moh plantaion, Lampang, producing 450,000 seedlings per year. Most of seed sources for farmers in Lampang are from unidentified seed sources in Serm-ngam district of Lampamg province. None of the small farmers use seed from improved seed sources such as clonal seed orchard. There is one private company that uses teak seedlings from tissue culture of selected mother trees but their number is not known. The FIO produces 50,000 seedlings from its tissue culture facility using genetically improved material mostly for its own plantations but the rest of 400,000 seedlings produced by it for sale are from unidentified sources. The RFD uses mostly seeds from unidentified sources for its nurseries with only a small amount of seeds originating from clonal seed orchard that are largely used in its own plantations.

Thus, only a very small portion of teak seedlings use in Thailand is from genetically improved seed sources. Fortunately, in 2018 the Research and Development Bureau under the RFD initiated a scheme under the ITTO Teak in Mekong training program to produce 70,000 clonal seedlings from top ten Plus trees selected after full-sib progeny test for their growth and tree forms. These seedlings are meant for small farmers in Ban Huad sub-district group as stock plants for producing their own new high-quality seedlings. The ITTO Teak in Mekong training program not only benefits the project country partners but also a timely help for small farmers to learn and practice how to produce their own high quality seedlings.

Plus Tree Selection

Passing the discrete units of *inheritance*, or *genes*, from parents to offspring is a fundamental theory of *inheritance* (Miko, 2008).

Good offspring, therefore, must come from selected parent trees. In order to obtain the desired characteristic of trees in plantations the seedlings to be planted must be propagated from Plus trees. Characteristics of Plus trees selection are dependent on the end use of the wood produced from the plantations. Since teak fetches highest prices when usable as veneer, marine decking, furniture, etc., its stem form and wood texture are, therefore, important traits for selection. The criteria to select stem form are straightness, clear bole and axis (Piyapant, 2001). Trees that are straight with long clear bole, cylindrical axis, with less taper are desirable. Branch characteristics that affect stem form are size and angle. Smaller branch and perpendicular angle trend to better prune naturally resulting in longer clear bole. Wood texture could be identified by the pattern of bark. Straight stripe pattern determines the desired straight grain of wood inside while spiral pattern indicates twisted grain of wood that degrade the wood quality. Sample of plus tree and selection process is shown in Photo 9-1.

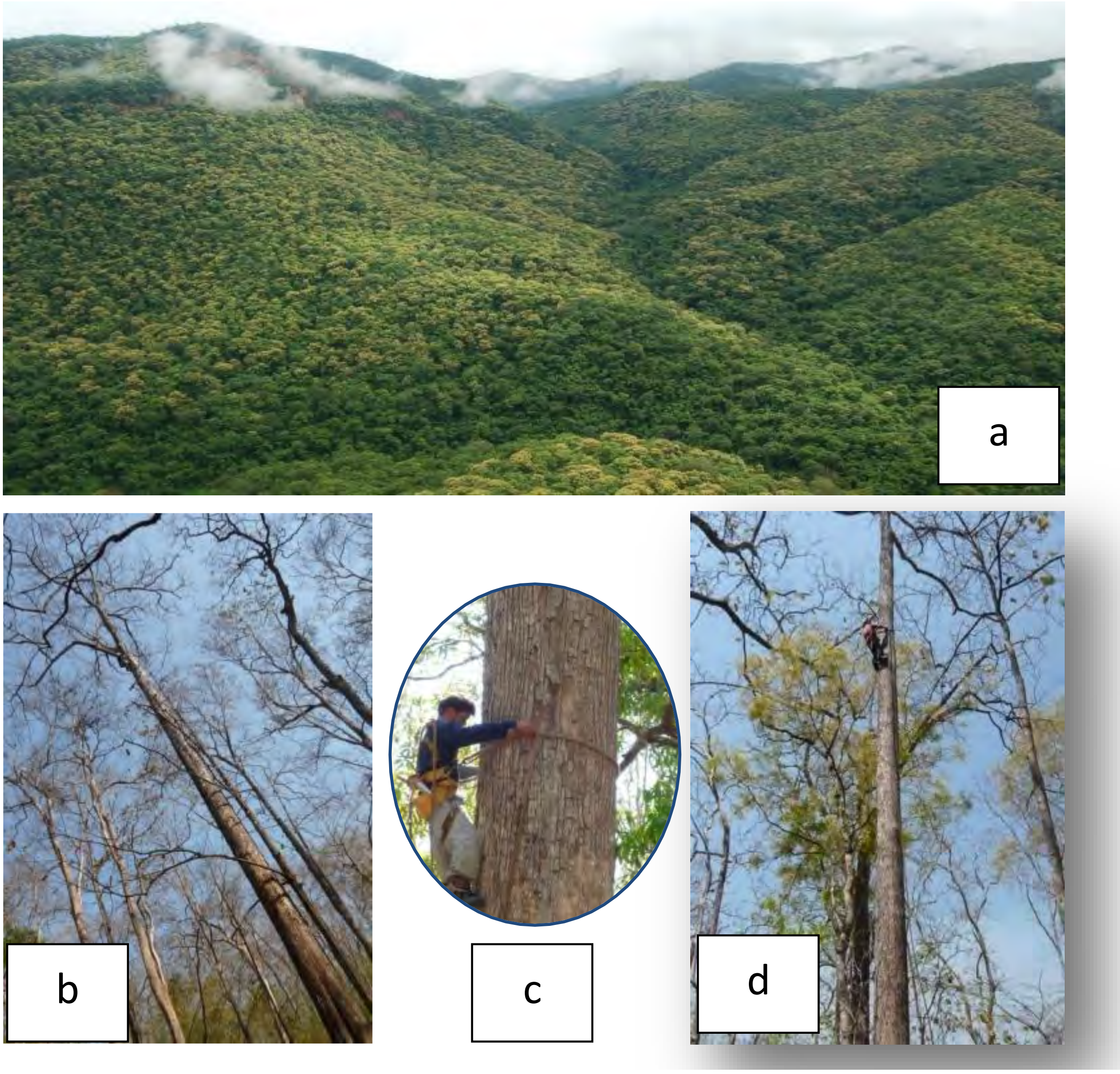


Photo 9-1 Plus tree selection
a) Natural teak forest as genetic resource
b) Sample of plus tree
c&d) Safety climbing to collect branch of plus tree for propagation

High buttress is more difficult to log when harvesting and also leads to increased harvesting losses in wood volume. No, or low buttress, is, therefore, the desired trait for selection. The buttress, however, often occurs where a tree grows on loose soil in order to provide stronger anchor which is a desired trait.

When selecting Plus trees the selector must look closely on the tree trunk from all directions, from near and afar. Health of the tree is also taken into consideration when selecting Plus trees. Trees with signs of borer attack or fungi attack are avoided. Another important character is the growth of the tree which is easier while selecting Plus trees in old plantations that enable comparison of relative growth in candidate trees because they are the same age and in same environment, except for the border trees which grow bigger because of less competition. Selection from natural forest, on the other hand, is less reliable due to different environment the candidate plus trees encounters since germination until selection. The biggest and the highest tree is chosen giving due importance to the height up to which marketable timber can be obtained. At least 15 meter commercial height is prescribed for Plus trees. The location of the Plus tree selected should be digitally recorded by using GPS and the information shared with field staff with instructions to avoid any damage to the tree and prevent its removal.

The phenotype of Plus tree selected is the outcome of its genetic traits x environment interactions during its growth. Therefore, after selection, the Plus tree must be examined to verify its higher genetic values in clonal tests. A total of 636 plus trees were selected in Thailand from both plantations and natural forests throughout the country. These Plus trees were propagated and planted in clonal banks, tested through clonal tests, established in clonal seed orchards, and tested for their progeny performance in the form of full-sib and half-sib progeny tests.

Propagation Techniques of Teak Used in Thailand

Propagation by Seed

Propagation by seed is the easiest technique to propagate teak because it is the natural method of propagation (Kaosa-ard, 1983a). Majority of plantation in Thailand were propagated by seeds using both bare rooted and containerized seedlings. Bare root seedlings are called “stumps” which are prepared from 1-year-old seedlings raised in seed beds by cutting the stem and lateral roots off retaining only the tap root with one or two buds (Lauridsen, 1973; Lauridsen & Kaosa-ard, 1973). When the climate is more stable and plantation site is far from motorable road, stump planting is more practical and popular. Nowadays, potted seedlings, produced directly from seeds or from stumps, are more often used due to variable weather. Potted seedlings can be produced from stumps sized less than 0.7 cm in diameter which is not suitable for direct planting. Direct sowing of seeds to produce potted seedlings is possible but needs greater care and carries high risk of failure in germination and therefore, not a popular method among small farmers.

Application in teak improvement program

Seeds are the product of the ripened ovule in mother, after fertilization by pollen from the father (Anon, 2019a). Genetic values in seeds are, therefore, inherited from both father and mother trees. The offspring performances vary depending upon what aspects are controlled by the parent gene. The progeny can thus both be worse or better than its parent in some specific respects. This fact is utilized in tree improvement when better off springs are selected for next generation the seeds of which are the end products of the program and are used to produce seedlings for the establishment of seedlings seed orchard (Piyapant, 2001). Seeds from these seed orchards then become the main genetic materials for plantation.

Vegetative propagation

Seedlings propagated using other parts of plant besides seed, or cloning, will maintain the same genetic characteristic as mother plant (Anon, 2019b). These techniques, therefore, does not improve genetic traits of plants but can be used to multiply the already improved ones. There are many techniques to vegetatively propagate teak such as budding, rooted cutting and tissue culture. Each technique has advantages and disadvantages and, therefore, suitable technique should be used in order to gain the highest benefit.

Budding technique is the method that uses grafting scion bud onto stock plant. The new plant is developed from the scion bud using root system of the stock plant. T-budding was the first technique used in Thailand before Forkert and Open-two-flap techniques were developed. Open-two-flap technique is used with bigger and more succulent buds from the clone bank. Open-two-flap was very successful and used for a long time until Chip-patch technique was developed which lends itself to very fast paced application and is mostly in use now (Keiding & Boonkird, 1960a; Keiding & Boonkird, 1960b; Bryndum, 1969; Hedegart et al., 1974; Sumantakul, 1980; Kaosa-ard, 1983b).

Planting stock for teak budding

At the beginning of the Teak improvement program stock plants were planted in clone bank and clonal seed orchard 1 year prior to budding procedure. The success was very low and uneven. Later stumps of 1- year old seedlings were successfully used as planting stock (Hedegart et al., 1974). Size of stump should be the same size as scion. To prepare stumps for budding, 1–3-year-old-seedlings are taken from seedling beds, lateral roots pruned, and stem topped at about 20-25 cm height. Chip-patches, about 3-5 cm long, are slit just above root collar and grafted with scion bud patch (Pianhanurak et al., 1996). Stump can be stored up to 3 days covered with moist sand before budding (Piyapant, 2001).

Scion bud

The most suitable bud for grafting is the one that just starts to sprout. Selection of Plus tree, therefore, must be done during March to April when the bud of teak starts to sprout (Hedegart et al., 1974). Buds taken from newly flush shoots (1-2 years) are easier to graft and the buds taken from outer crown produce shoots that shows more twig characteristic than the one taken from inner crown (Boonkird, 1964). Branches that contain suitable buds are harvested and brought back to nursery for grafting, kept in a sack and stored in cool place. They can be kept under moist rice husk for a month without damage (Piyapant, 2001). When grafting on root stocks, the buds are cut in the same shape and size as the chip-patch of the root stock and then placed on to the slit part of the stock. The two parts are then tied together by plastic sheet leaving only the bud exposed (Pianhanurak et al., 1996).

Raising of budded stumps

After planting the budded stumps in containers, the buds are covered with a small plastic bag to prevent moisture loss from the bud (Pianhanurak et al., 1996). The budded stumps are then raised in a nursery with 50 percent shade (RFD, 2013). Watering must be done regularly until the buds sprout in about 1-3 weeks and all shoot sprouts must be removed from the root stock. When the scion buds sprouts, the plastic cover bag should be removed to let the new shoot grow freely and prevent sunburn (Piyapant, 2001). The budding technique is shown in Photo 9-2.

Photo 9-2 Teak budding process by patch grafting techniques
a) Preparation of root stock from 1 year-old bare root seedlings
b) Graft scion bud patch onto slit stock and tie with plastic rope
c) Cover the budded seedling with plastic bag and planted in media then kept in nursery
d) Remove plastic bag after budded sprout, and get rid of buds sprouted from root stock

Disadvantages of budding technique

Incompatibility due to the different growth rate of stock plant and scion, or fungal infection at the joining part, sometimes slow down the growth rate and even kill the scion shoot (Piyapant & Pianhanurak, 1994). Regular removal of sprout from stock plant must be carried out to make sure no sprout from stock grows over the scion shoots.

Application of budding technique in teak improvement program

Thailand has often used budding technique to establish clone bank, seed orchards, and clonal test but where rooted cutting and tissue culture of teak is possible, budding technique is not preferred. Budding technique is not recommended for propagation in a clonal test because the root system does not belong to the tested plant.

Rooted cutting: A piece of the stem or root of the source plant is placed in a suitable medium such as moist soil. If the conditions are suitable, the plant piece will begin to grow as a new plant independent of the parent, a process known as striking. A stem cutting produces new roots, and a root cutting produces new stems (Anon, 2019c). In teak it is more difficult to induce root in mature branches than in juvenile material. For propagation by cuttings of old Plus trees, the branch identified for cutting must first be rejuvenated

(Pianhanurak et al., 1996) through serial budding, tissue culture, serial cutting, or hedging. For maintaining juvenile nature of stock plants, hedge orchard of teak must be planted in small plastic bag instead of planting in the field (Pianhanurak & Pianhanurak, 2000; Pianhanurak & Pianhanurak, 2002; Pianhanurak, 2002; Piyapant, 1999). The quality of cut material in the controlled environment is a critical factor affecting rooted cutting of teak. The cutting materials must be juvenile, age not more than 4 weeks after pruning, size of stem less than 0.5 cm in diameter, leaves thin, soft and covered with hair (Pianhanurak, 2002). To prepare cuttings, leaves are trimmed to about one-third size to reduce transpiration, then apply rooting hormone for 10 second before being kept in rooting media.

Environment control

Non-mist propagators consisting of bamboo frame covered with plastic sheet are used to control relative humidity of the air around the cuttings. Moisture content in rooting media is controlled by watering until very wet before striking the cutting. Temperature is controlled by providing shade by a plastic sheet around the rooting chamber and spraying water during the day when the weather is hot. It is more desirable to do cutting in rainy season since the weather is suitable for plant growth. If nothing goes wrong roots will develop after one month (Pianhanurak, 2002). The rooting procedure is illustrated in Photo 9-3.

Photo 9-3 Rooted cutting processes of teak from rejuvenated materials
a) Preparation of rejuvenated shoots by trimming off half leaves and applied rooting hormone
b) Preparation of rooting media in non-mist propagators
c) Temperature and humidity controlled during rooting period
d) Gradually remove shade to get full sunlight when the seedlings establish

Application of rooted cutting technique in teak improvement program

After the success of the rooted cutting of teak, it was applied in many occasions.

1. Prepare seedlings for 5 sets of clonal tests which aim to evaluate the genotypic value of plus trees by planting a range of them in the same environment (thus removing "environment" as a factor in determining their physical properties). The genotype ×environment interactioncan be examined by replicating the clonal test at different sites. Ultimately, the top-ranking clones can be selected and propagated, for either deployment in plantations or additional improvement.

2. Clone bank where collection of plus trees are planted, plus trees number 1 – 400 were propagated by budding technique, from number 401 and so on were propagated by cutting technique. 3 clone banks that established in 2009, the seedlings were also propagated by rooted cutting.

3. The technique was used in combination with tissue culture to produce special teak that harvested to build the Giant Swing in 2006. 200,000 seedlings were tissue cultured as parent materials then propagated by cutting to produce up to 1,000,000 seedlings of the special trees to give out to people.

4. At present when new improved materials were selected, tissue culture is used to produce stock plants then cutting is the main activity to mass propagate teak for distributing seedlings to farmers.

Tissue culture is a technique in which small tissue pieces or organs are removed from a donor plant and cultured aseptically in a nutrient medium (Anon, 2019d). There are four steps to do tissue culture of teak. First step is sterilizing of explants into initial stage medium. Second is the initial stage when the tissue adjusts to new environment to be ready for the multiplication stage and rooting stage. Third is the multiplication and rooting stage with a growth hormone added to the media when the tissue becomes plantlet ready to be multiplied or rooted. The last stage is transferring of plantlet to potting soil for further growth in the greenhouse as normal plants (Kyte, 1990).

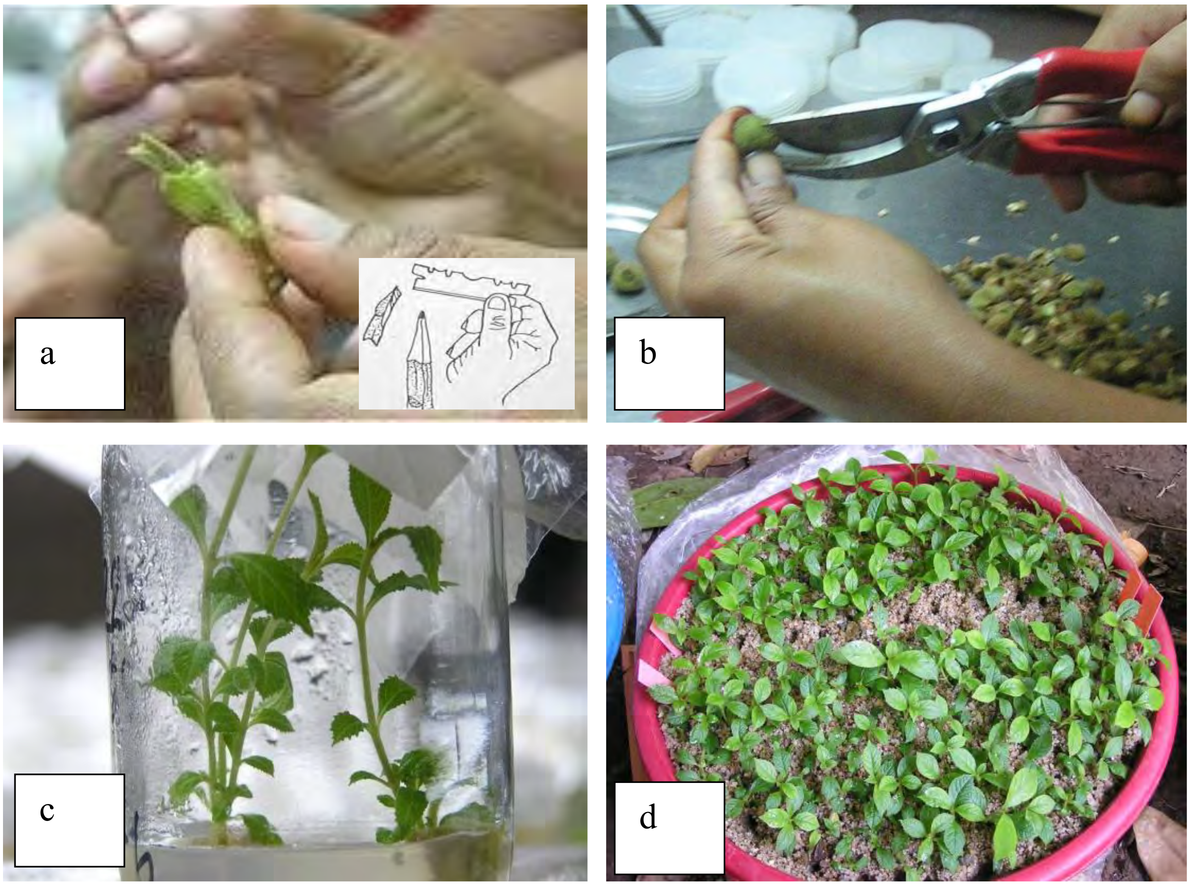


Photo 9-4 Tissue culture processes of teak
a) Sterilize technique of young shoot
b) Sterilize technique of young seed
c) Teak tissue in multiplication stage
d) Out planting of plantlets to nursery

Explant of teak could be young seed, mature seed, axillary bud or shoot meristem. Each explant needs different technique to sterilize and manipulation during initial stage. Once the tissue reach multiplication stage they all need the same treatment (Pianhanurak, 2003). Medium for culturing teak is Murashige and Skoog (MS) media (Murashige. & Skoog, 1962) with Benzene Adenine Purine (BAP) 0.5 mg, Kinetin (Kn) 0.25 mg per liter and 7 percent agar for multiplication and without hormone or with Indole Butyric Acid (IBA) 1 mg or Naphthalene Acetic Acid (NAA) about 0.5 mg per liter in rooting stage (Pianhanurak, 2003) When transferring to nursery, however, the plantlet does not need root. It is easier and more effective to cut plantlet above agar level and root the plantlet in planting media. The same environment control as rooted cutting is required for transplanting the plantlet. The process of teak tissue culture is illustrated in Photo 9-4.

Application of tissue culture technique in teak improvement program

The technique requires skill, experience, high technology equipment and high cost. Plant to be propagated by this technique should have high genetic value and selected for planting on large scale since mass production will reduce its cost. There are also risks due to cleanliness of the laboratory and stabilization of electric supply to the laboratory. If these risks are not controlled, the lab may lose a lot of tissue to contamination with microorganisms. It is suggested to use tissue culture to produce juvenile stock plants for rooted cutting.

Lessons Learned and Recommendations

Plus tree selection is the most important step of tree improvement program. Criteria and standard of selection should be set up carefully based on each country's situation and expectations. The number of Plus trees to be selected should be as large as possible depending on the budget and human resources. Selection should be done throughout the available genetic resources, even exchanging the genetic material across the countries of the Mekong sub-region, in order to provide widest genetic base to the improvement program. Training in vegetative propagation by budding technique should be organized before the selection of Plus trees so as to collect materials for propagation as soon as a Plus tree is selected deep in remote forests to avoid frequent visit to the Plus tree again soon after selection.

Propagation by seeds is the easiest technique and it plays an important role in the improvement program as small farmers use this technique to produce their seedlings. It is, therefore, recommended to establish more of high quality seed sources such as seed orchard to produce enough high quality seeds for plantation. Often small farmers use seeds from unidentified seed sources even as seeds from Clonal Seed Orchards (CSO) remain stored in seed centers until their viability is lost. To promote use of CSO seeds, they should be given free of cost, or at very low costs, to the farmers.

Teak can be vegetatively propagated by various techniques. Budding is the most successful when propagating mature material because the budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture. The technique is, therefore, recommended for application in first stage propagation of Plus trees subsequent to which other techniques can be used if needed. It is not advisable to use budded seedlings directly to establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. This is best carried out in combination with rooted cutting or tissue culture. The main purpose of budding is to rejuvenile mature materials before exposing to cutting or tissue culture for large scale multiplication of planting stock.

Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak. It is less successful when mature materials are used. In the establishment of clone bank, clonal test, or clonal seed orchard where a large number of clones but only a few seedlings per clone are involved, it is recommended to use budding technique to first rejuvenate mature materials and then undertake rooted cutting of the juvenile shoots to produce seedlings. In the case of mass production of elite plants, it is recommended to use tissue culture to mass produce juvenile stock plants for rooted cutting. When there are enough stock plants, rooted cutting is more powerful than tissue culture.

Conclusion

Selection of plus trees should be done carefully and thoroughly to cover all available resources. Criteria and standard for selection must be set up properly to get the right trees for improvement program. Using the right technique of propagation in every step of improvement program is the key to the success of genetic improvement of teak. Budding technique by Chip-patch technique is the most successful when propagating mature material. Budded shoots are rejuvenated and become suitable for carrying out rooted cutting or tissue culture, the technique is, therefore, recommended for application in first stage propagation of Plus trees subsequent to which other techniques can be used as needed. It is not advisable to use budded seedlings to directly establish clone bank, clonal test, or CSO due to the concerns of incompatibility and possible contamination of root stock plants if budded shoots have not been monitored properly. Rooted cutting is the cheapest, most successful, and easiest method to propagate juvenile material of teak but is less successful when mature materials are used. In the establishment of clone bank, clonal test, or clonal seed orchards, where a large number of clones but only a few seedlings per clone are involved, it is recommended to use rooted cutting of the rejuvenile shoots to produce seedlings. In the case of mass production of elite plants, it is preferable to use tissue culture to produce juvenile stock plants for rooted cutting. When there are enough stock plants, rooted cutting is more useful than tissue culture.

References

Anon. (2019a). *Seeds.* https://en.wikipedia.org/wiki/Seed. (accessed by 20 August 2019).

Anon. (2019b). *Cloning*. https://www.thaibiotech.info/what-is-cloning.php (accessed 20 August 2019).

Anon. (2019c). *Plant Cutting*. https://en.wikipedia.org/wiki/Cutting_(plant) (accessed 20 August 2019).

Anon. (2019d). *Tissue Culture*. https://www.shutterstock.com/th/search/plant +tissue+culture?page=2 (accessed 20 August 2019).

Boonkird, S. (1964). Progress report on the first teak tree-show in Thailand. *Natural History Bulletin of the Siam Society,* 20(4), 243-256.

Bryndum, K. (1969). Budding of teak. *Indian Forester,* 95(3), 155-157.

Hedegart, T., Wangtara, B. & Yingvanasiri, T. (1974). Budded/Potted Teak Stock. *The Vanasarn*, 32(4), 337-341.

Kaosa–ard, A. (1983a). *Nursery Techniques of Teak*. Forestry Review, No. 2 May 1983. Silvicultural Research Sub-Division, Royal Forest Department, Bangkok, Thailand.

Kaosa–ard, A. (1983b). *Teak Improvement Programme Annual Report*. Nos. 15–16. October 1980–September 1982. Silvicultural Research Sub-Division, Royal Forest Department, Bangkok, Thailand.

Keiding, H. & Boonkird, S. (1960a). Vegetative Propagation of Teak. *Unasylva,* 14, 193-194.

Keiding, H. & Boonkird, S. (1960b). *Budding and grafting of teak*. Document, third session of the Teak Sub-commission, New Delhi, India.

Kyte, L. (1990). *Plant from Test Tubes. Timber Press*, Portland.

Lauridsen, E. B. (1973). Teak plants survive and grow well after storage. *T.I.C. Report 1973*, TIC, Ngao, Lampang.

Lauridsen, E. B. & Kaosa-ard, A. (1973). Underground storage of teak stumps. *T.I.C. Report 1973*, TIC, Ngao, Lampang.

Miko, I. (2008) Gregor Mendel and the principles of inheritance. *Nature Education,* 1(1), 134.

Murashige, T. & Skoog, F. (1962). A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physio Plant*, 15(6), 473-497.

Pianhanurak, C. (2003). *Teak Tissue Culture Techniques*. Academic documents accompanying requests for assessment of persons to be forest academics positions 8 W**.** Technical group, Protected Areas Regional Office 13, Department of National Parks, Wildlife and Plant Conservation, Bangkok, Thailand. 107 p.

Pianhanurak, P. & Pianhanurak, C. (2000). Special Techniques and Some Important Factors on The Success of Mature Teak Cutting in Non-mist Propagators. In *Annual report on Silvicultural Research year 2000.*, pp. 177-189. Silvicultural

Research Division, Forest Research Office, Royal Forest Department, Bangkok, Thailand.

Pianhanurak, P. & Pianhanurak, C. (2002). Hedge Orchard Management for Rooted Cutting of Teak Plus Tree. In *7th Silvicultural Research Seminar Proceeding on Silvicultural Practice for Economics Plantation,* 12-14 December 2001. Silvicultural Research Division, Forest Research Office, Royal Forest Department. Bangkok, Thailand.

Pianhanurak, P. (2002). *Rooted Cutting Technique for Genetic Improvement of Teak*. Academic documents accompanying requests for assessment of persons to be forest academics positions 8 W. Silvicultural Research Division, Forest Research Office, Royal Forest Department, Bangkok, Thailand. 77 p.

Pianhanuruk, P., Piyaphan, P. & Pianhanuruk, C. (1996). *A Preliminary Study of Rejuvenation of Teak by the Budding Technique*. ASEAN Forest Tree Seed Centre, Saraburi, Thailand. 7 p.

Piyapant, P. & Pianhanurak, C. (1994). *Effects of clones on budding methods on Incompatibility and Fungal Infection in Teak* (*Tectona grandis* Linn.) *at 4 Different Ages,* pp. 1-8. Academic-documents accompanying requests for assessment of persons to be forest academics positions 7 W. Silvicultural Research Division, Forest Research Office, Royal Forest Department, Bangkok, Thailand.

Piyapant, P. (1999). *A Preliminary Study on Rejuvenationof Teak by the budding technique*, pp/ 9-16. Academic documents accompanying requests for assessment of persons to be forest academics positions 7 W. Silvicultural Research Division, Forest Research Office, Royal Forest Department, Bangkok, Thailand.

Piyapant, P. (2001). *Teak Improvement in Thailand*. Academic documents accompanying requests for assessment of persons to be forest academics positions 8 W. Silvicultural Research Division, Forest Research Office, Royal Forest Department, Bangkok, Thailand. 179 p.

RFD (Royal Forest Department). (2013). *Thai Teak Knowledge*. Thailand's Agriculture and Co-operatives Printing Ltd, Bangkok. Thailand. 302 p.

Sumantakul, V. (1980). *Teak Improvement Center Progress Report*. October 1978-September 1979. TIC Ngao, Lampang, Thailand. 18 p.

Chapter 10: Technique for Controlled Hand-Pollination of Teak (*Tectona grandis* L.f.)

Suwan Tangmitcharoen

Abstract

Teak plantation has been expanding rapidly, resulting in an increased demand for the high-quality seed. Thailand has begun a tree improvement program since 1965. Although seed orchards exist, the demand for improved quality seed and planting stock exceed supply. Plus tree selection and clonal tests were established throughout the range of Thailand. Fortunately, efforts have been made to breed and test these selected clones. To accomplish the breeding strategy, effective and cost-efficient techniques for controlled pollination are necessary. This paper is based on controlled pollination of teak conducted since 1992 mainly at the ASEAN Forest Tree Seed Centre in Saraburi province and a teak seed orchard at Phayao. It provides information on background information i.e. phenology, pollination fruit set, seed development, materials and supplies required for hand pollination, planning the pollination activities, hand-pollination technique, monitoring of fruit set including practical constraint and recommendations. These should be of benefit to all breeders or researchers involved in teak improvement programs and related research. The information also could provide field staff with the current knowledge of teak flowering and to serve as a "how-to" guide for controlled hand-pollination of teak.

Introduction

To meet the fast-increasing demand for high-quality seed in Thailand, the Royal Forest Department (RFD) has begun an intensive tree improvement program based on the extensive seed orchards and seed production areas established in northern Thailand since 1965. Although approximately 2 016 ha of seed orchard exist, the demand for improved quality seed and planting stock far exceeds supply.

The clonal orchards have been established by bud grafting and cutting techniques selected individuals from native stands throughout the range in Thailand. Effort has been made to breed and test these selected clones. The RFD also plans to test over 500 selected clones, and strategies have been designed to promote hybrid vigor and to test the breeding population using full-sib and half-sib mating. To accomplish this, effective and cost-efficient techniques for controlled pollination are necessary.

This chapter on controlled hand-pollination is based on controlled pollination of teak conducted from 1992 to 1996 at two locations, a plantation near the ASEAN Forest Tree Seed Centre (AFTSC) in Saraburi Province and a teak seed orchard at Payao in northern Thailand, under a study involving production of full-sib families from controlled-crossing pollination of teak (Tangmitcharoen et al., 2001) and from a review of existing literature. The objective is to provide field staff with the current knowledge of teak flowering and to serve as a "how-to" guide for controlled hand-pollination of teak.

Background

Phenology of teak

The phenology of teak varies across its natural range depending on the climatic conditions. In India, for example, new leaves appear in June and July followed by the flowering period during September and October. Fruit development ends in November and maturation in March while fruit shed occurs during April and May (Seth & Kaul, 1978). In Indonesia, flowering occurs in February and March, followed by fruit development in April and May. Fruits mature during June through August and fruit is shed in September (Palupi, 1996). In Thailand, teak flowering occurs during July and August and the fruits mature from November through February with seed fall occurring in March and April (Hedegart, 1976).

The source of the planted stand growing at the AFTSC in Muak-Lek, and used for this study, was northeast Thailand. In Muak-Lek, leaf shedding occurs November through January and the trees remain leafless through the hot, dry season. The new leaves appear in April through June. The trees begin to flower a month earlier (in June) than in the north. Flowering continues through the first half of the rainy season and ends in August. The fruit matures from September to February and is shed during the hot, dry season from March to April. Bryndum & Hedegart (1969) have suggested that since flowering occurs during the rainy season, heavy rains are likely to have a deleterious effect on pollination.

Floral morphology

Unlike most other tree species, teak begins fructification with an inflorescence emerging on the main axis of a young tree (Syrach-Larsen, 1966). The inflorescence is a large panicle containing up to a few thousand flower buds. As only 1-3% of the flowers in an inflorescence bloom each day, anthesis for the entire inflorescence occurs over a 1-to-2-month period, depending on the size. Flowers are small (6-8 mm in diameter), whitish, actinomorphic, and hermaphroditic. The lower half of the corolla is undivided, forming a tube to which 6-7 stamens are attached (Photo 10-1). The pistil is composed of a hairy ovary containing 4 ovules and a long (6.55 mm), narrow, bifurcate style with a forked stigma. The forked stigma is of the wet papillate type with unicellular papillae (Bryndum & Hedegart, 1969; Tangmitcharoen & Owens, 1997a).

Photo 10-1 Inflorescence and flower: Large panicle of teak inflorescence showing high rate of fruit abortion, which commonly occurs in self- and open pollination (left); Teak flowers at receptivity showing six stamens and petals and straight style; and, one day after receptivity after corolla abscised (right)

Receptivity and stigma development

The phenology of individual teak flowers during the day of receptivity is provided in Box 1. Individual flowers are weakly protandrous. Anthesis begins at 0700 h with anthers starting to dehisce at 0800 h, approximately 3 hours before the corolla is completely open and stigma receptivity begins (11.00 h).

The peak receptive period for teak flowers is 1100 to 1300 h. The bent style is the first organ to emerge as the flowers open. It fully extends between 1100 and 1300 h and exceeds the length of the anthers. Corollas begin to abscise about 1900 h, or earlier in windy conditions, and about 95% of the open corollas are shed by 2300 h.

Box 1 The phenology of individual *T. grandis* flowers during the day of receptivity.

Time of day	Events
0400	flowers closed; style coiled
0500	nectar forms within the lower part of the corolla
0700	flowers begin to open
0800	anthers begin to dehisce
1100-1300	peak receptive period •corolla completely open •style straight •stigma reflexed and turgid •hydration of pollen on stigma
1500	post-receptive period -stigma tip dry and collapsed
1700	anthers collapse, nectar disappears
1900	corolla begins to shed

Source: Tangmitcharoen & Owens (1997a)

Pollen morphology and pollen germination

Pollen is medium tricolpate but varies somewhat in size and shape depending on the amount of hydration. Dehydrated pollen is semiangular, ranging in size from 12-29 µm (average 19.94 µm) as seen in polar view, and oval, perprolate to prolate, ranging in size from 24.24-48 µm (average 39.79 µm) in equatorial view. Shortly after landing on the stigma, pollen hydrates and expands due to secretion presented by the stigma papillae. Hydrated pollen is spherical to oblate or suboblate in both polar and equatorial views, and ranges in size from 16.8-36 µm (average 28.84 µm). Pollen kitt (a sticky coating) is often found on the mature teak pollen surface, particularly during the early receptive period (1100 h). Pollen released at 1100 h (4 hours after anthesis) has the highest viability (92.2%). Pollen viability gradually decreases after 1100 h. Three days (84 hours) after flower opening, pollen is no longer viable (Tangmitcharoen & Owens, 1997b).

Pollination and fruit production

Many studies have reported that teak is insect-pollinated (Horne, 1961; Bryndum & Hedegart, 1969; Cameron, 1968; Egenti, 1974; Kedarnath, 1974). In Thailand, two bee species, *Heriades binghami* and *Ceratina hirrglyphica* are reported to be the main pollinators, although various kinds of flies and butterflies are also implicated (Bryndum & Hedegart 1969). Tangmitcharoen & Owens (1997a) found that the major pollinators are *Ceratina* sp., which carry teak pollen on most parts of their bodies, but especially on the tibia. They collect pollen by foraging on several newly opened flowers in one inflorescence and travel among inflorescences and trees. Most, however, tend to forage and stay on the same tree for a long period of time.

In large teak plantations, low populations of pollinators and self-pollinations are thought to be the causes of poor pollination success. In trees located near roads in roadside plantations, and in agricultural fields, fruit production can be high, possibly as a result of a greater number of pollinators, favorable site conditions (Suangtho & Lauridsen, 1990), and a higher incidence of cross-pollination.

In general, fruit production following open pollination is low compared to that obtained in controlled cross-pollination. Based on investigations carried out at the Teak Improvement Center (TIC) during 1962-72, natural open pollination resulted in only 0.4 - 5.1% (average 1.3%) of flowers developing into fruits. Studies on controlled pollination in teak were pioneered by Bryndum & Hedegart (1969) who described a procedure for controlled pollination using small bags to isolate single flowers and large bags stretched over a bamboo frame to isolate an entire inflorescence. The first success of controlled hand-pollination was reported by Hedegart (1973). He indicated that with hand-pollination, the percentage of flowers developing into fruits increased from 6 to 60% (average 20%). Tangmitcharoen & Owens (1996) also reported success of hand controlled cross-pollination (14.54%).

Fruit and seed development

Palupi (1996) found that fertilization occurs within 24 hours of pollination. The early endosperm develops soon after fertilization and fills the whole embryo sac within 1 week after pollination. The zygote starts to develop into a proembryo 3 days after pollination.

The major cause of fruit and seed abortion is failure in endosperm development. Undeveloped early endosperm causes zygote abortion, and a lack of, or abnormal, endosperm development results in embryo abortion. Palupi also suggested that failure in endosperm development may be attributed to selfing. Teak ovules reach their maximum size 8 to 11 weeks after pollination, which coincides with the maximum fruit diameter. The maximum embryo size is reached 14 to 16 weeks after pollination when the cotyledons become thick and fill the ovule cavity. Fruit moisture content is declining during this period, indicating the end of the seed development stage and the beginning of the maturation stage.

The period from flowering to fruit maturation in Thailand varies between 4 and 7.5 months, which is similar to that in northern India (7-8 months) (Seth and Kaul 1978), and that in Indonesia (6 months) (Palupi, 1996). In all three locations, flowering occurs during the rainy season and fruit reaches maturation in the dry season. In northern Thailand, fruits develop to full size approximately 50 days (about 7 weeks) after pollination and another 70-150 days (10-21 weeks) is required for maturation, for a total of about 120-200 days (17-28 weeks) (Hedegart, 1976).

Types of pollination

Natural or open pollination implies no human interference, while controlled pollination requires some human input. Though controlled pollination can be conducted in various ways depending upon the objectives, hermaphroditic flowers are generally subjected to the following treatments:

Type of pollination	Treatments
Natural (open)	no human manipulation
Controlled	•flowers isolated from foreign pollen by bagging •flowers bagged and emasculated (anthers removed)
Self —autogamous	flowers not emasculated, pollen from the same flower applied
—geitonogamous	flowers emasculated, pollen from different flowers of the same tree applied
Cross —allogamous	flowers emasculated, pollen from another tree applied

Materials and Supplies Required for Hand-Pollination

Controlled hand-pollination activities are fairly complex and are usually conducted in areas, such as clonal seed orchards, where immediate access to equipment, materials and supplies is limited. Advanced planning and purchase of required materials and supplies is critical to ensure a smooth operation. Access to flowers must be ensured and pollination supplies must be available and prepared.

Reaching the flowers with scaffolding

To conduct controlled pollinations, it is necessary to have easy access to the flowers and to be able to spend time safely and reasonably comfortably within the flowering crown. Fixed scaffolding is probably the most effective method. Scaffolding can be made of bamboo or steel. Bamboo is an inexpensive material; however, it is rather difficult to erect and usually deteriorates after about 1 year of use. On the other hand, steel scaffolding (Photo 10-3) is more expensive initially, but is easy to erect, is very secure, and does not deteriorate with time. It is more economical in the long run. The number of sections required depends on the height and form of the tree, intensity of inflorescence in the canopy, and size of inflorescence. Each section provides about 1.7 m of height. An adjustable base, which allows easier and more secure scaffold installation, is highly recommended.

Photo 10-2 Access to flowers of 40 year-old teak using street scaffolds which should be elected soon after emerging of flower bud (July)

Isolating the flowers with pollination bags

To exclude natural pollinators and ensure only the chosen pollen is available to the flowers to be bred, the flowers must be isolated with pollination bags. Of the various types of pollination bags, cellophane or fine mesh nets has been found to be appropriate. It can also be obtained easily from an ordinary stationery store.

Identifying and marking flowers for pollination

Inflorescences and flowers within inflorescences must be identified and well-marked or tagged so that there is no doubt about the pedigree of the fruit when it is mature. The tags must be unique and durable so that the identity of the pollen parent is known throughout the process. Color-fast, light weight, pliable yet durable crochet string has been found to be suitable. The yarn comes in spools of many colors. The string should be cut into approximately 6-in. lengths to ease tagging work. If colors are limited, a combination of two or more pieces of the same color or a combination of colors can be used to increase the number of individual labels.

Handling and manipulating flowers with forceps

Teak flowers, particularly the stamens, anthers, pistils, and stigmas are very small and fragile. The recommended way for handling and manipulating the flowers is by using forceps. Forceps should be approximately 4-5 in. long with a fine point and should be nonsticking.

Observing pollen on stigma

Observation of pollen adhering to the stigma may be required to ensure the success of pollen application and to investigate the success of emasculation to ensure no contamination with self-pollen on each stigma The use of a 10x magnifying glass in the field will help determine pollination success. Flowers may be collected and taken to the field office where the use of a zoom stereo microscope will provide a clear image of the stigmatic surface.

Planning the Pollination Activities

Controlled pollinations conducted within breeding programs are very time sensitive. The window for pollination is often short so advanced planning of all aspects is critical. A mating or breeding plan which identifies clones to be tested must be in place, ramets must be selected; access to adequate numbers of inflorescences and flowers achieved, and staff training in the pollination techniques must be provided.

The breeding plans

The strategies for the breeding and testing of clones within the tree improvement program must be clearly defined. Conducting controlled hand-pollinations is a very time-consuming operation and it is likely that only a few clones can be bred and tested each year. To test the entire available population may take several years. The orchards will have to be well mapped with each tree clearly identified by clone and provenance of origin. In addition, it is important that detailed phenology of each clone be available. To date there is no information for pollen storage of teak so controlled pollination will be with fresh pollen. Synchronization of the flowering period of pollen donor and mother tree is obviously an important consideration when selecting clones for each year's pollination program. The annual breeding plan must clearly outline which clones are selected as pollen donors, which clones are selected as mother trees, and which pollen parents are to be crossed with each selected mother tree. To ensure an adequate number of seeds are available for progeny testing, each specific cross has to be repeated many times over the course of a breeding season.

Selection of ramets

The breeding plan will outline which clones are to be tested each year. Within each clone, a number of ramets are available and choices must be made. Criteria for ramet selection will vary depending on materials and supplies available. The following should be considered when choosing ramets:

- pollen parents and mother trees should be reasonably close as travel between the two will be required
- ease of accessibility to the trees and flowers, i.e. near road or trail and on reasonably level ground to facilitate scaffold construction
- sufficiently mature with a history of flowering in the recent past so that adequate numbers of inflorescences are likely to be produced. It may be that more than one ramet of each clone will be required to ensure an adequate number of inflorescences. The use of substantial branches on mature ramets is essential to complete fruit maturation. Small branches of recent grafts may not be capable of providing sufficient

nutrients throughout the 4 to 7.5 months of fruit development.

- crown size and height of tree should be reasonable to facilitate access.

Timing and erection of scaffolding

Scaffolding must be erected on both pollen donor tress and mother trees so flowers for pollen can be collected, and controlled hand-pollination can be conducted. Although the clones and the ramets will have been selected in advance, it is recommended that scaffolding be erected after the appearance of sufficient inflorescences to complete the pollination work. Setting up scaffolding prior to visible inflorescences is risky since some selected ramets may not produce sufficient flowers to meet needs.

The scaffolding should be erected and placed so that an adequate number of inflorescence (10 to 20) is easily accessible, and the climbing and pollination work can be conducted in an unhindered fashion. Wooden platforms should be installed at appropriate levels on the scaffolding to provide some comfort, and the scaffold structure should be firmly attached to surrounding trees with guy-wires if height exceeds 7 m (4 sections) to ensure complete safety. Guy-wires should be well flagged to prevent injury.

How much can be accomplished in a day?

Due to the short daily receptive period (1100-1300 h - see Box 1), one person can expect to hand-pollinate only about 30-60 flowers a day depending on experience. Approximately 7-15 flowers per inflorescence open each day. Thus, around five inflorescences on a single mother tree should be selected for every day of pollination. Selection and marking of inflorescences and flowers within inflorescence will be completed in the early morning. As only 1-3% of the flowers in an inflorescence bloom each day, pollination work will likely be done every day for about 1 month to complete the breeding plan. Inflorescence can be repeatedly used, due to newly opening flowers; however, if sufficient inflorescences are available, it is better to use new inflorescences each day to avoid damaging the previously pollinated flowers.

Preparation of pollination bags

Cellophane or fine mesh nets is appropriate materials for making pollination bags. Cellophane is available in sheets of 31 x 34 in. To make pollination bags, the cellophane sheets are cut in 2 pieces (31 x 17 in.) and each piece is folded to produce a bag of 15.5 x 17 in. The two sides are held together with transparent tape. A few smaller sized bags should also be prepared for use on smaller panicles.

The number of pollination bags to be prepared will depend on the number of trees to be tested and the number of inflorescences per tree available for pollination on a daily basis. The cellophane pollination bags can be used twice but are prone to breakage with greater use. The required number of bags per tree will be about 75 (5 inflorescenes x 30 day ÷2). It is best to ensure that more than enough pollination bags are available for the pollination program.

Record keeping

Keeping accurate and detailed records of all pollination activities and having excellent clone maps is an absolute necessity. The truism" if in doubt, throws it out" should never be heard. Detailed records, i.e., a diary, should be kept on a daily basis. Initially, all activities and problems encountered, as well as weather, should be recorded. During the period of pollination, details on daily pollen donors, pollen collection time, mother trees selected, inflorescence and flowers chosen, cross-pollinations made with identifying string colors, time of emasculation and pollination, weather at the time of pollination, and any problems (e.g. with equipment or supplies) should be recorded as well. A well-kept diary may help to explain variation in seed set, will ensure the pedigree of all genetic material (mature fruit), and will be of great benefit in subsequent years to reduce operational problems.

Training staff in pollination techniques

Hand-pollination of teak is meticulous and tedious work. Staff cannot become skilled and effective quickly. It is necessary to clearly demonstrate the technique both in the lab and in the field prior to pollination activities. Special emphasis and care must be placed on the emasculation, bagging, and pollen application procedures. Intensive training at the beginning will lead to successful pollinations.

Pollination success

Tangmitcharoen & Owens (1997b) suggested that pollination success was greater in flowers which opened during the early and peak flowering seasons than in those which opened at the end of the flowering season. As such, to catch the early flowering season, all the preparations, including the breeding plan, selection of ramets, staff training, equipment and supplies, must be completed in advance and be fully operational as the trees begin to flower.

Hand-Pollination Technique

The following tasks are listed in order of daily occurrence:

Selecting inflorescence and flowers on the mother tree

As pollination success is greater during the early and peak flower seasons, pollination should be done only on those flowers which bloom in these seasons, i.e. only on those flowers on the innermost or proximal portion of the inflorescence. The most distal flowers on an inflorescence should not be pollinated as little success will occur. Selection of flowers on an inflorescence should be done prior to flower opening, i.e. by 0700 h.

Marking flowers

Individual flowers must be marked to record the pedigree of the cross. As recommended earlier, flowers should be marked, tagged, or labeled using colored string. At the time of selection in the early morning (by 0700 h) on the day of pollination, the appropriate colored string is tied to the pedicel (Photo 10-3) of each unopened flower that is to be pollinated. Different colors are used to identify both pollen parent and day of pollination. Tagging should be done carefully and lightly to avoid damaging fragile flowers.

Photo 10-3 Marking flowers using colored string tied to the pedicel of an unopened flower. Marking should be completed by 07.00 h

Installing pollination bags

The pollination bags of various sizes have been prepared in advance. The purpose of pollination bags is to isolate the flowers that are to be pollinated that day from pollinators so there is no chance of contamination. The cellophane pollination bags are placed over the group of open flowers (approximately 7-15 flowers per inflorescence) to exclude all potential pollinators (Photo 10-4).

Photo 10-4 Pollinated flowers are enclosed in a cellophane bag to exclude all potential pollinators. The bag should be removed the following day

Emasculating treatments

Anthers of flowers to be used as female parents have to be removed prior to bagging to eliminate the possibility of self-pollination. Using fine forceps, the undehisced stamens are removed from the newly opened flowers between 0600 and 0700 h on the day of pollination. Emasculation should be conducted gently and carefully to avoid dispersion of pollen from anther to stigma of the same flower.

Pollination bags should be attached as soon as possible after emasculation and marking of flowers to prevent pollen contamination from any insect visitors. If more than one bag is contemplated (maximum 2) on an inflorescence, great care must be taken to avoid breaking inflorescences and the pollination bags should be positioned on opposite sides. Plastic wrapping string is used to secure the bag to the inflorescence and to close the open end of the bag.

Collecting flowers from the pollen donor

Though pollen released at 1100 h has the highest viability (92.2%) (Tangmitcharoen & Owens (1997b), flowers should be collected as they open, i.e. 0800 - 0900h. As dry windy weather will cause pollen to dehisce, early collection of pollen-donor flowers ensures that the pollen will remain in the anthers. Early collection also provides time to prepare for pollination activities.

Flowers are carefully and gently cut at the pedicel using fine forceps. Removal of flowers should be done gently to avoid dispersion of pollen from the anthers. Ensure that more than enough flowers are collected to pollinate all the flowers on each mother tree. Pollen-donor flowers are used only once so it is necessary to collect at least one pollen-donor flower for each mother-tree flower to be pollinated that day. Collected flowers from the same tree can be stored together in a small plastic container. The container must be handled and stored carefully to avoid contamination by insect visitors or damage from wind and rain. The container can be stored at ambient temperature in the shade without any special treatment since pollen viability remains high until approximately 1500 h (Tangmitcharoen & Owens, 1997b). The container must be well identified with the pollen parent.

Pollination treatments

All receptive flowers (7-15) within each bag will be given the some treatment. Within each bag, all the flowers will be controls (pollen excluded), self-pollinated, or cross-pollinated. During the time the pollination bag is off the flowers, it is important to keep natural pollinators away from the flowers.

Photo 10-5 Controlled pollination by brushing an anther against the stigma of a receptive flower

Pollen application at mother tree

Pollen application should be conducted at the peak of the receptive period, i.e.1100 h (Box 1). Each bag is temporarily removed, one at a time, from the receptive flowers for about 10-15 minutes for hand-pollination. A pollen-donor flower is grasped by the calyx with the forceps. The anthers are then rubbed on the receptive stigmas of the marked flowers to be pollinated (Photo 10-5). To ensure that sufficient pollen is transferred, all six anthers on a flower are rubbed on the receiving stigma. The pollen-donor flower is then discarded. This operation is repeated using another pollen-donor flower on another marked flower until all open marked flowers in the bag have been pollinated.

Reinstall pollination bag

After applying pollen, pollination bags are reinstalled. It is necessary to reinstall the bags immediately upon completion of pollen application to each individual group of flowers to avoid contamination. To prevent build up or heat, which would damage the stigma, the bag and pollinated flowers should not be in contact with one another. After reinstallation, the next inflorescence can be pollinated.

Removal of pollination bag

Since fertilization occurs within 24 hours after pollination, the bag should be removed the day following pollination.

Monitoring of fruit set

After controlled, self-or cross-pollination, the flowers are observed through fruit development until maturity (every day for the first month and every week thereafter). The purpose of regular monitoring is to record fruit set, fruit abortion, and, if possible, the causes of fruit abortion. Generally, the rate of fruit abortion is relatively high during the first two weeks following pollination and possible causes of fruit abortion (insect damage, wind, heavy rain) can usually be determined. During this time, fruit development should be monitored and recorded daily. After fruit reaches full size (5 0 days), fruit abortion gradually decreases. Observation can be done every week thereafter until fruit maturation Causes of fruit abortion should be recorded throughout the study.

Practical Constraints

Loss flowers or fruit after pollination

Premature loss of fruit after pollination can occur for different reasons. Common events, causes, and some suggestion to reduce loss are identified in Box 9-2.

Box 9-2 Causes and suggestions to reduce premature loss of flowers and fruit

Events	Cause	Suggestion
Broken inflorescences with pollen bag attached	strong wind, heavy rain	• choose light material for making pollination bag, i.e. cellophane • remove bags the day after all of the open flowers in the bag are pollinated • support inflorescence weight by tying inflorescence to main branch
Fruit damage	insects feeding on fruit	• apply insecticide to inflo rescence
Unusual loss of pollinated flowers	using the outermost flowers of the inflorescence at the end of flowering season	• use flowers which open during the early and peak flowering seasons • use only flowers which occur in the main body of inflorescence

Ideally, fruit set from cross-pollination should be high. This, however, may not be true for many tropical forest species. Poor fruit set may be caused by three factors: an artifact of hand-pollination (Bawa et al., 1985), a predetermined abortion rate (Bawa & Webb, 1984), and inbreeding depression from close relative cross-pollination (Haber & Frankie, 1982). In teak, these factors may have contributed to relatively high (80-85%) fruit abortion with cross-pollination (Hedegart, 1973; Tangmitcharoen & Owens, 1997b; Tangmitcharoen et al., 2001).

Delay of pollination operation due to poor weather

Since the peak of the flowering season of teak occurs during the rainy season, rain is an unavoidable obstacle to pollination work On a rainy day, hand-pollination cannot be conducted Cloudy weather may delay flower-opening time, anthesis, and the receptive period. As such, the controlled pollination operation should be flexible to coincide with anthesis and receptivity.

Worker expertise

Hand-pollination of teak flowers is tedious and time-consuming work. Success of fruit set can vary depending on the attention and expertise of personnel who are conducting pollination Personnel effectiveness can be enhanced with proper training, good support, and a secure platform on which to work.

Conclusion

Controlled pollination is one of the procedures of teak breeding program essential to produce new breeds of selected clones for producing upgraded genetic materials. Therefore, effective and cost-efficient techniques of controlled-hand pollination are necessary. RFD has conducted teak controlled pollination since 1992 and already successfully produces ten new breeds and producing some of these improved genetic materials to the tree farmers. This paper which composed of major activities of hand controlled-pollination such as information related to pollination, materials and supplies required for hand-pollination, planning of pollination activities, hand-pollination technique, fruit set monitoring including practical constraints could be supported as a manual on conducting controlled-cross pollination. It also could provide field staff with the current knowledge of teak flowering and to serve as a "how-to" guide for controlled hand-pollination of teak and should be benefit to all breeders involved in teak improvement programs and related research.

References

Bawa, K. S. & Webb, C. J. (1984). Flower, fruit and seed abortion in tropical forest trees: implications for the evolution of paternal and maternal reproductive patterns. *American Journal of Botany,* 71(5), 736-751.

Bawa, K. S., Perry, D. R. & Beach, J. H. (1985). Reproductive biology of tropical lowland rain forest trees. I Sexual systems and incompatibility mechanisms. *American Journal of Botany,* 72(3), 331-345.

Bryndum, K. & Hedegart, T. (1969). Pollination of teak (*Tectona grandis* L.f). *Silvae Genetica,* 18, 77-80.

Cameron, A. L. (1968), Forest tree improvement in Papua New Guinea. In *Proceeding from the 9th Commonwealth Forestry Conference.* New Delhi, India.

Egenti, L.C. (1974). *Preliminary studies on pollinators of teak* (*Tectona grandis* L.f.). Research Paper No.29. Research Paper Forest Series. Federal Dept. For. Res, Nigeria.

Haber, W. A. & Frankie, G. W. (1982). Pollination of *Leuken* (Tiliaceae) in Costa Rican deciduous Forest: significance of adapted and non-adapted pollinators. *Ecology,* 63, 1740-1750.

Hedegart, T. (1973). Pollination of teak (*Tectona grandis* L.) 2. *Silvae Genetica, 22*(4), 124-128.

Hedegart, T. (1976). Breeding systems, variation and genetic improvement of teak (Tectona grandis L.f). In *Tropical trees, variation, breeding and conversation, Linn. Soc. Symp. Series 2*. (eds. J. Burley & B.T. Styles), pp. 109-124. Academic Press, New York, USA.

Horne, J. E. M. (1961). Teak in Nigeria Nigerian Forestry Infor. Bull. (New series) 16.

Kedarnath, S. (1974). Genetic improvement of forest tree species in India. *India J. Genetics. Proc. 2nd General Congress, Sarrao*, New Delhi, India. 34p.

Palupi, E. (1996). *Reproductive biology of teak* (*Tectona grandis* L.) *in East Java, Indonesia*. MSc thesis. University of Victoria, B.C., Canada.

Seth, S. K. & Kaul, O. N. (1978). *Tropical forest ecosystem in India: The teak forest in tropical forest ecosystems*. Natural Resources Research, XIV, UNESCO, Paris.

Suangtho, V. & Lauridsen, E. B. (1990). *Flowering and seed production in Tectona grandis* L. Report on the DANIDA Training Course on Tree Improvement Program. Changmai, Thailand. 33 p.

Syrach-Larsen, C. (1966). *A teak tree show*. Nat Hist Bull. of the Siam Society, Bangkok, Thailand.

Tangmitcharoen, S. & Owens, J. N. (1996). Floral biology, pollination and pollen-tube growth in relation to low fruit production of teak (*Tectona grandis* Linn.f.) in Thailand. In *Tree Improvement for Sustainable Tropical Forestry* (eds. M.J. Dieters, A.C. Atheson, D.G. Nikles, C.E. Harwood, & S.M. Walker), pp. 265-270. Proceedings of QFRI-IUFRO Conference, 27 October- 1 November. Queensland Forestry Research Institute, Gympie, Caloundra, Queensland, Australia.

Tangmitcharoen, S. & Owens, J. N. (1997a). Floral biology, pollination, pistil receptivity, and pollen-tube growth of teak *(Tectona grandis* L.f.*). Annals of Botany,* 79, 227-241.

Tangmitcharoen, S. & Owens, J. N. (1997b). Pollen viability and pollen-tube growth following controlled pollination and their relation to low fruit production in teak (*Tectona grandis* Linn.f.). *Annals of Botany,* 80, 401-410.

Tangmitcharoen, S., Ponoy, B. & Pianhanuruk, P. (2001). *Producing of full-sib families from controlled-crossing pollination of teak* (*Tectona grandis* Linn.f.), pp.128-138. Silvicultural Research Report 2001. Silviculture Research Division, Forest Research Office, Royal Forest Department, Bangkok (in Thai).

Annex

Glossary of terms used in the in text

Definition marked *, #, and @ are adapted from the Chambers Biology Dictionary, W & R Chambers Ltd and Cambridge University Press, 1989; The Concise Oxford Dictionary of Botany, Oxford University Press, 1992; and the Penguin Dictionary of Botany, Market House Books Ltd, 1984, respectively.

	Actinomorphic	**Radially symmetrical.**
@	Allogamy	(Syn cross-fertilization, exogamy) Fusion of female and male gametes derived from genetically dissimilar individuals of the same species.
*	Autogamy	Fertilization involving pollen and ovules from (1) the same flower or sometimes (2) the same plant or genetically identical individuals (same genet or clone).
@	Cross-pollination	The transfer of pollen from the anthers of one individual of the same
*	Geitonogamy	Fertilization involving pollen and ovules from different flowers on the same individual plant (ramet) or from the same clone (genet).
@	Hermaphroditic	Having both male and female reproductive parts in the same flower.
@	Panicle	A racemose inflorescence in which the flowers are formed on stalks (peduncles) arising alternately or spirally from the main axis. The term is also sometimes used to describe any type of complex, branched inflorescence.
@	Papillate	A projection from a cell, usually of the epidermis. Papillae are often swollen and covered with wax. In xerophyte, a plant adapted to dry habitat, where growth may be limited by water shortage.
@	Pedicel	The stalk attaching individual flowers to the main axis (peduncles) of the inflorescence. The pedicel may act as a temporary storage organ for sugars prior to seed development.
	Perprolate	Elliptic shape (more oval than prolate).
	Prolate	Elliptic shape.
#	Protandry	The maturation of the male reproductive organs before those of the female. For example, in many members of the Legumenosae the pollen is released from the anthers before the stigma in the same flower is
#	Raceme	A racemose inflorescence in which the flowers are formed on individual pedicels on the main axis (peduncle).
@	Racemose inflorescence	An inflorescence in which meristematic activity continues at the apex of the main stem and primary laterals and flowers are developed from the axillary meristems. Different types of racemose inflorescence include panicle, corymb, raceme, umbel, and spike.
#	Self-pollination	The transfer of pollen from anther to stigma of the same tree (either of the same flower or of a different flower but always of the same individual).
@	Tricolpate	Describing a pollen grain having three colpi (oblong to elliptic germinal apertures), as is commonly found amongst most dicotyledon species.

Chapter 11: Teak-Based Pest and Disease Management in Myanmar

Thant Shin, Zaw Min Aye and Myo Htet Aung

Abstract

Major teak pests in Myanmar are leaf skeletonizer, teak bee-hole borer, and teak leaf defoliator. In natural forests the teak pests are kept under control through ecological balancing by the natural enemies of these pests but with the proliferation of teak plantations the insect and pest problems has attained serious proportions. Teak leaf skeletonizer, *Eutectona machaeralis* Walker, is the biggest concern that reduces growth rate of teak significantly. Is larva feeds on the green leaf tissue between the networks of veins, leaving the skeleton of veins intact. Partially damaged leaves are not shed and even the fully skeletonized leaves are retained by the tree for some time. Teak bee-hole borer (*Xyleutes ceramicus* Walker) is another major insect pests of teak in both natural forests and plantations. Application of jaggery solution near the larvae to attract the ants is an often practiced biological control. Rust caused by *Olivea tectona* and leaf blight caused by the fungus Rhizoctonia solani also causes significant damage during the early stages of the plant. Mistletoe, a hemi-parasite, which can be controlled only by labour intensive branch cutting, has become a major problem for teak plantations in Bago Yoma Region of Myanmar.

Introduction

Serious efforts to raise large scale teak plantations in Myanmar began in the 1970s and in 1998 the "Special Teak Plantation Program" was launched across the country with the specific objective of planting teak on a very large scale to ease pressure on the natural teak forests. In 2007 private forest plantations were also allowed throughout Myanmar and since then private teak planting at commercial scale has picked up.

In natural forests the teak pests are kept under control by ecological balancing by the natural enemies of these pests but with the proliferation of teak plantations the insect and pest problems has attained serious proportions. Major pests in teak plantations in Myanmar are leaf skeletonizer, teak bee-hole borer, and teak leaf defoliator. In the raining season of 2021, an extensive teak leaf skeletonizer outbreak was reported from the central region of Myanmar including the Bago Yoma Region. Fungus diseases, such rust, powdery mildew, have also been observed in the nurseries of Pauk Khaung Township, Pyay District during the field trip to the project site in January 2022. Mistletoe has also become a big problem especially for aged teak plantations.

Major Pests in Teak Plantations and Management

Teak leaf skeletonizer

Teak leaf skeletonizer, *Eutectona machaeralis* Walker, is one of the major pests of teak plantations in Myanmar. The larva feeds on the green leaf tissue between the networks of veins, leaving the skeleton of veins intact. Partially damaged leaves are not shed and even the fully skeletonized leaves are retained by the tree for a short period of time. This pest decreases the growth of teak trees. The life cycle from egg to the moth ranges from 17 to 18 days. In Myanmar, 13 generations are completed per year under the laboratory condition (Myint et al., 2016). The female moth usually lays the eggs singly on the underside of teak leaves from 203 to 374 in average and a maximum of 500 to 550 (Nair, 2007).

The most feasible control measure is to collect the infected leaves and burn them.

Solution of 200 oz of dry tobacco leaves and 50 oz of vegetable soap in the ratio of 4:1 in 100 gallons of water stored for 24 hours could also be used as a biological insecticide (Beeson, 1941).

Teak bee-hole borer

The teak bee-hole borer (*Xyleutes ceramicus* Walker) is one of the most serious insect pests of teak in both natural forests and plantations. The larvae penetrate the teak stems about the size of the bee's head, and hence the name "teak bee-hole borers". The larvae and silkworm life are spent inside the trunk. The adult bee-hole borers get out of the stem and start the life cycle again. While they come out from the trunk, part of their body is left hanging at the hole.

One management option is applying 100 EC Malathion on a cotton swab to close the hole of this pest. The larvae can also be killed by inserting a galvanized wire into the hole. As biological control, sugar or jaggery solution is applied near the larvae to attract the ants, their natural enemies.

Major Diseases in Teak Plantations and Management

Rust

The rusts caused by *Olivea tectona* are a group of fungal diseases affecting the teak leaves. The main method of disease spread is via spore movement, mostly by wind or through transport of infected material. This fungus penetrates through lower surface of leaves which gets covered with bright orange spores within a short period of time. Brown to grey angular areas of dead tissues appears on the upper surface of leaves corresponding to spores masses on the lower surfaces of leaves (Osorio et al., 2019).

Measures that could be taken to eradicate this disease from old growth, the use of fungicides, would be highly undesirable from an environmental and social perspective and they would be virtually impossible to apply effectively and economically. In nursery, the infected seedlings can be segregated and kept in isolation. Severely infected and dead seedlings can be burnt away from the nursery to prevent the spread of the disease. The disease may be controlled in the nursery by the application of sulphur based fungiside (Sulfax) on both sides of the leaves.

Leaf blight

This disease caused by the fungus *Rhizoctonia solani*. The disease develops on teak leaves particularly under humid conditions by producing reddish-purple or tan spots that coalesce to form large lesions. Developments of greyish brown blotches increase in size with the advancing fungal hyphae and ultimately spread on the entire leaf blade. The disease is spread by wind and is highly infectious under prolonged periods of high humidity.

Mistletoe

Mistletoe, a parasitic plant, belongs to the Lornthus genus. However, they are beneficial as a key species that fill in the ecological niche for wildlife, especially for birds. They penetrate into the teak branches and absorb the food and water of the teak plant, and they also photosynthesis by themselves. Mistletoe in teak plantations belong to the "hemi-parasite" family. They decrease the growth and stamina of teak and then kill the teak plants. They spread by throwing the seeds from eating the colorful, sticky fruit of the parasites which were preferred by the birds and also through faeces.

Their spreading rate can be reduced by cutting the infected branches of teak trees. However, this control measure is very labour intensive and costly and rarely carried out on large scale. Therefore, mistletoe have become a major problem for teak plantations in Bago Yoma Region of Myanmar.

Photo 11-1 Teak Plantation damaged by *Eutectona machaeralis* Walker

Photo 11-2 Young teak stem and branch damaged by *Xyleutes ceramicus* Walker

Photo 11-3 Adult *Eutectona machaeralis* Walker

Photo 11-4 Young teak stem and branch damaged by *Xyleutes ceramicus* Walker

Photo 11-5 Rust disease

Photo 11-6 Teak tree affected by Mistletoe

Conclusion

For successful implementation of commercial teak plantations, the priority should be given to the research activities of pest and disease. The working groups of pest and disease control should also be organized for at all levels of forest administration, i.e. Township, District, State and Divisional Forest Department. The participation of private forest owners is also important as a key stakeholder.

References

Beeson, C. F. C. (1941). *The Ecology and Control of the Forest Insects of India and the Neighboring Countries*. Indian Agricultural Research Institute, New Delhi, India.

Myint et al. (2016). *Effective Control Measures of Some Major Insect Pests in Young Teak (Tectona grandis Linn. F.) Plantations*. Yezin Forest Department, Myanmar.

Nair, K. S. S. (2007). *Tropical Forest Insect Pests: Ecology, Impact, and Management*. Cambridge University Press, Cambridge, UK.

Osorio, P. R. A., Leão, E. U., Ferreira, T. P. D. S., Alves, M. V. G., Sarmento, R. D. A. & Santos, G. R. D. (2019). Morphology and infection process of Olivea neotectonaein teak leaves. *Arquivos do Instituto Biológico*, 86(2), 1-5.

Chapter 12: Insect Pest Management in Teak Plantations in Thailand

Wattanachai Tasen and Decha Wiwatwitaya

Abstract

Teak beehole borer and teak insect defoliator are the most important pests of the teak plantations in Thailand. A study on sustainable teak pest management in the forest plantations was carried out in northern Thailand. The objectives were to provide update of the teak pest incidence and control measures to reduce the insect population in teak plantations. The growth and destructive behavior of teak beehole borers and teak defoliator were investigated. The design of protection and control measures suggested in this study can be used to solve the problem of teak insect pests more effectively.

Introduction

Teak (*Tectona grandis*; Family Lamiaceae) is one of the famous and the most important commercial timber species in many tropical countries in Asia (Thailand, Myanmar, Lao PDR, Indonesia, Sri Lanka, Bangladesh and India); West Africa (Ghana, Nigeria, Ivory Coast, Senegal, Togo and Benin); East Africa (Sudan and Tanzania); Central America (Trinidad and Tobago, Puerto Rico, Panama and Costa Rica); and South America (Brazil and Ecuador) (FAO, 1957; FAO, 2001; Kaosa-ard, 1981; Kaosa-ard, 1995; Keogh, 1996; Pérez Cordero & Kanninen, 2003). Teak is a high-priority planting species for plantations in the Asian region, especially in India, Myanmar, Indonesia and Thailand (Kaosa-ard, 1995). At present, the demand for teak timber and green space is increasing year by year. The supply so far met from the remaining natural forest is fast depleting and threatens its natural resource base. One solution to overcome the present shortage is to establish more teak plantations in suitable habitats.

Teak is an economically important timber both for household sector and the forestry industry. For the past couple of decades, investments in teak plantations has attracted large-scale private plantation developers. The pest problem of teak has been reported in many areas from the seedling stage to the felling cycle. There are about 300 species of pests and diseases recorded in teak, including order Coleoptera, Lepidoptera, Orthoptera, Hemiptera, Isoptera, Diptera and Hymenoptera (Beeson, 1961; Hutacharern et al., 1988; Hutacharern & Tubtim, 1995; Nair, 2007). These insects attack all stages of teak growth (Roychoudhury & Mishra, 2021) hence, special care is required from the first year of planting. Insects that attack include termites, caterpillars, ants and some aphids. In India, Roychoudhury & Mishra (2021) reported that a teak pest of the genus Holotrichia spp. (Coleoptera: Scarabaeidae) or white grubs has invaded teak seedlings in nurseries, teak defoliator, *Hyblaea puera* Cramer (Lepidoptera: Hyblaeidae) and leaf skeletonizer, *Eutectona machaeralis* (Walker) (Lepidoptera: Pyralidae), are considered as major pests of teak in plantations and natural forests. Another group of insect pests such as defoliators, stem and branch borers also destroy teak and its final yield and productivity as well.

Current Scenario of Teak Pests in Thailand

In Thailand, there are about 72 species of teak pests (Hutacharern et al., 1988; Hutacharern & Tubtim, 1995), of which about half a dozen species of teak defoliators, stem borers, flower and fruit eating insects are more important causing significant damage to the teak. The classification of forest pests is based on the intensity of infestation which Chaiglom (1966) organized into seven groups of forest pests, namely, leaf feeders or defoliators, trunk and branch borers or beehole borers, root feeders, inflorescence destroyers, shoot borers, sap suckers, and seed and fruit insect pests. The insect pests that cause the most damage are usually stem-damaging insects or teak beehole borer and defoliating insects. A research project, Plant Genetic Conservation Project under the Royal Initiation of Her Royal Highness Princess Maha Chakri Sirindhorn (RSPG), has been initiated to prepare guidelines to manage, prevent, control and reduce pest populations to a level that does not cause economic damage to teak plantations. It focuses on two major insect pest groups namely, teak beehole borers and defoliators.

Observation Updates and Management Practices

Teak beehole borer

Teak beehole borer (*Xyleutes ceramicus,* Family Cossidae, Order Lepidoptera) is considered the most important pest in the teak plantations causing extensive damage to wood texture ultimately reducing market demand and forcing sale at discounted prices. This wood borer has been recorded only on teak (Wiwatwitaya, 2000) and widely distributed in many countries where teak is planted such as Burma, Thailand, Indonesia, Malaysia and India (Beeson, 1961; Hutacharern et al., 1988). The insect leavesa large hole in the wood about 8-12 mm in diameter and 20-38 cm long (Chaiglom, 1966). The penetration is cumulative, indicating its recurrence every year. As a result, the teakwood quality is lost and the timber cannot be sold at premium prices (Wiwatwitaya, 2000). In infestations reported in 3-year-old teak and older, the occurrence of penetration can be from close to the ground to the top of the trunk. Chaiglom (1966) found that this insect reaches adult stage during February - May.

The beehole borer female may lay upto 50000 eggs that have an incubation period of about 7 days and may live in the wood as larva for 1-2 years. Pupation takes place about 2-3 weeks before the emergence of an adult depending on the location; for example, Sukhothai province during February and Lampang Province in March. The life cycle and destructive behavior of teak beehole borer in some locations are still unclear. This study focused on growth and destructive behavior of teak beehole borer in Northern Thailand (Wang Chin teak plantation in Phrae Province and Mae Li teak plantation in Lamphun Province) was conducted in 2018-2019. The related environmental factors in each month were also investigated.

Beehole borer impact on teak plantations

The growth of beehole borer in north-east and north-west plantations had different growth stages. Its growth is faster in North-east indicating the pupate stage in November than in north-west plantations where it was still in the pupa stage. The emergence of the adults began in December at north-east part of the Wang Chin Forest Park. Hutacharern & Tubtim (1995) found that teak beehole borers become adults during February -March. The borer is found in the North-west plantation between December and January and in North-east plantation between January and April. The caterpillar stage is observed from January to April of the following year. In the North-east plantation, the larvae persists for a longer period. As the radial growth of teak at north-east plantation was found faster, it was believed that the caterpillars received more food from the younger tissues and become adults within a short time.

The 4th larvae stage destroyed the heartwood to a greater extent during the active growing season between May to November. The sapwood was destroyed between March and August. During the dry season between December to April, there was no destruction of wood. The long bore tunnel in the heartwood remain in the trunk and sawnwood recovery is affected.

Photo 12-1 Study on teak beehole borer in plantation

The natural enemies of teak beehloe borer are mostly ants, followed by tachinid flies and parasitoid wasps. Wiwatwitaya (1996) reported that ants *Crematogaster* spp. and *Anoplolepis longipes* were most dominant predators of the borer. Mortality of teak borer was more pronounced in the early stage, the fifth stage, and the pupa stage. Mortality was highest at the time when the larva is about to pupate because at this time it reaches near the exit point where its natural enemies can enter the hole. This is also the period of dry summers when no fresh tissue develop to cover the wound around the sapwood and the holes are not closed unlike when the teak plant is still growing.

Teak defoliators

There is another group of insect pest defoliators that requires constant monitoring and prevention in teak plantations. Despite several research studies over the past many decades the biology, ecology, its natural enemies and the use of pesticides for elimination, the problem of defoliation has not subsided. Interactions with researchers and field staff of many forest plantations suggests there are on-going outbreaks in many areas, in particular, the teak defoliator *Hyblaea puera* of the family Hyblaeidae. The teak skeletonizer, *Eutectona grandis* (Family Pyralidae), was found in northern areas of Lampang and Phrae and Phayao provinces. The biology and behavior of this insect epidemic group may have got modified due to the climate change as well. Altered interactions with natural enemies may be another factor affecting the population dynamics of teak defoliators.

Insect defoliators completely eat up the fresh emerging teak leaves causing retardation of the growth of the tree and wood production. Kritsanamara (1982) found that if teak lost 100 percent of the leaves, it would lose 87 percent of the wood growth for that period. About 28 species of defoliators have been reported

(Hutacharern et al., 1988 Hutacharern & Tubtim, 1995) causing considerable damage to teak leaves. *Hyblaea puera* is widely found in teak plantations throughout the north and other parts of Thailand. In addition to teak leaves ashost, *H.puera* are also found to feed on other plants such as mangroves like *Rhizophora* sp., *Avicenia* sp., *Bruguiera* sp., *Millingtonia hortensis* L.f. and *Oroxylum indicum* (L.) Kurz as well as *Fernandoa adenophylla* (Wall. ex G.Don) Steen, *Markhamia stipulate* Seem, *Vitex canescens* Kurz, *Vitex glabrata* R.Br. and *Vitex peduncularis* Wall.ex Schauer (Lakanavichian & Napompeth, 1990). *Hyblaea puera* completes its life cycle in 4 stages, taking a total of 2-4 weeks. Its outbreak usually spreads in late April –May during pre-monsoon rains when fresh leaves emerge and eat away the leaves leaving behind only the central and large veins.

Eutectona grandis (Family Pyralidae) finds hosts in the leaves of several species including *Callicarpa arborea* Roxb and is often found to infest teak later at the end of the rainy season between August to November. In the caterpillar stage it begins by eating the leaf surface until only the leaf veins are left forming a mesh like structure. When infestation is severe, the leaves will be reddish brown which is the color of dry teak veins. Outbreaks occur during the rainy season every year. Several natural enemies of teak defoliators *H. puera* and *E. machaeralis* are reported such as parasitoid wasps in the family Braconidae, Genus *Apanteles*, including *A. hyblaeae, A. malevolus, A. puera*, as well as in the genus *Cotesia* and *Dolichogenidea*. The chalcid wasps of the Chalcididae family are *Brachymeria euploeae* and *B. lasus* of which *B. lasus* has been reported as a natural enemy of the teak defoliator *H. puera* and *E. machaeralis*, and also the mahogany borer (*Hypsipyla robusta*), the parasitic leafworm (*Deliashyparate indica*), the pine borer (*Dioryctria abietella*), and *D. sylvesstrella* (Wiwatwitaya, 2000).

There are reports of studies on the use of biocontrol agents in the prevention of teak defoliators (Sudheendrakumar, 1986), in addition to pathogens that invade the defoliator such as *Bacillus thuringiensis, Enterobacteraerogenes, Serratiamarcescens* and *Pseudomonus aeruginosa*, and bacteria used to help eliminate teak insect pests. (Sudheendrakumar et al., 1988). Sakchowong (1998) studied two fungi, *Beauveria bassiana* and *Metarhizium anisopliae*, which cause disease on teak caterpillars.

Natural insect enemy of teak defoliators

A number of studies were carried out on the efficacy of natural insect enemies on decreasing population of teak insect defoliators in teak plantations in the north-western province of Lampun and in the north-east plantation sites in the Phrare province during 2018-2019. The damage caused by teak insect defoliators were classified in three separate categories of free feeding, skeletonizing, and stipping. The damage toteak defoliator at Mae Li teak plantation (28.50%) was higher than in Wang Chin teak plantation (25 %).

Total number of natural insect enemies enumerated were 54 species belonging to 25 families and 8 orders. The highest number of species was in Order Hymenoptera followed by Coleoptera, Diptera, Hemiptera, Blattodea, Mecoptera, Neuroptera and Dermaptera (21, 14, 10, 5, 1, 1, 1 and 1, respectively). The largest amount of natural insect enemies were found in north-west plantation (65.22 %) than in north-east plantation (34.78 %). This study showed that different land-use ecosystems influenced both quantity and species diversity of natural insect enemies and teak insect defoliators.

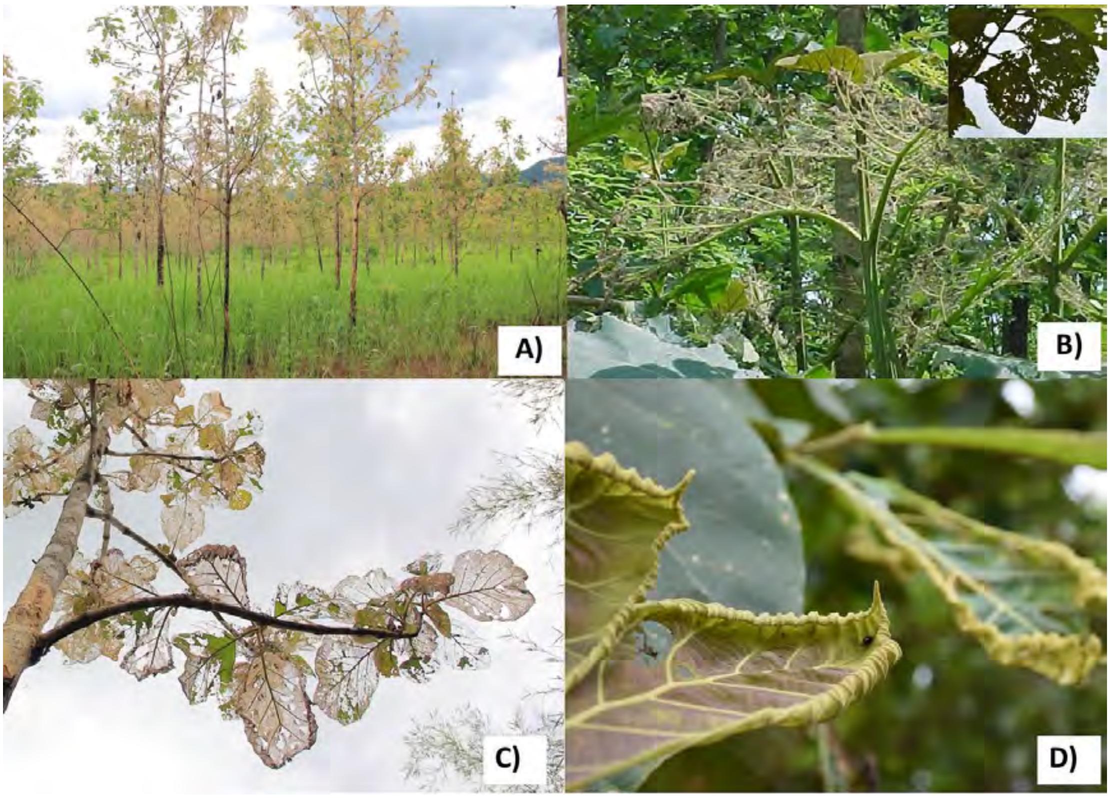


Photo 12-2 Defoliator damage; A-B) Free feeding C) Skeletonizing and D) Stipping

Conclusions

The destruction of the sapwood by the teak beehole borer was observed between March and August while the destruction of the heartwood was found to occur during May to November. Its most common natural enemy are the ants, especially *Crematogaster* species. Most mortality of the teak borer was found in the early stage, the fifth stage, and the pupa stage. The main natural enemies of the fifth stage and in the pupa, stage are parasitoid insects. Most death in pupa stage were caused by the parasitic tachinid flies. The data obtained from the study can be used to design more effective prevention and elimination of teak borer that suit the infestation and growth periods in teak plantation.

Insect defoliator showed three types of destruction, namely 1) free feeding (2) skeletonizing, and 3) stippling. Their natural insect enemies recorded are 54 species belonging to 25 Families under 8 Orders. Higher number of Hymenoptera was found in north-west plantations compared to north-east plantations. There is differences between the areas affected, number and diversity of natural enemies of teak insect defoliators. With the increasing incidence of insect defoliators, it is important to find new natural enemies to protect the teak plantations. For this insect surveys are required to be carried out to determine the impact of pest problem from teak seedling stage to the felling cycle.

References

Beeson, C. F. C. (1961). *The Ecology and Control of Forest Insects of India and Neighboring Countries*. Government Printing Office, India.

Chaiglom, D. (1966). Teak beehole borer and control research in Thailand. *Natural History Bulletin of the Siam Society,* 21, 1957-1960.

FAO. (1957). *Report on Teak Growing under Exotic Conditions*. FAO/TSC-57/3, FAO, Rome, Italy.

FAO. (2001). *State of the World's forests*. Food and Agriculture Organization, Rome, Italy.

Hutacharern, C. & Tubtim, N. (1995). *Check Lists of Forest Insects in Thailand*. Royal Forest Department, Bangkok, Thailand.

Hutacharern, C., Choldumrongkul, S., Eungwijarnpanya, S., Choldumrongkul, A. & Pholwicha, P. (1988). *Check Lists of Forest Insects in Thailand*. Royal Forest Department, Bangkok, Thailand.

Kaosa-ard, A. (1981). Teak (*Tectona grandis* Linn.f.) its natural distribution and related factors. *Natural History Bulletin of the Siam Society,* 29, 55-74.

Kaosa-ard, A. (1995). Management of Teak Plantations; Overview of problems in teak plantation establishment. In: *Teak for the future - Proceedings of the Second Regional Seminar on Teak,* pp. 45-59. 29 May - 3 June 1995, Yangon, Myanmar.

Keogh, R. M. (1996). *Teak 2000. A Consortium Support for Greatly Increasing the Contribution of Quality Tropical Hardwood Plantations to Sustainable Development*. International Institute for Environment and Development (IIED), London.

Kritsanamara, R. (1982). *The effect of leaf loss on the growth of teak plants*. MSc thesis, Kasetsart University, Bangkok, Thailand. (in Thai)

Lakanavichian, S. & Napompeth, B. (1990). *Ecological Study of Teak Defoliators. Hyblaea puera* (Cramer) *and Eutectona machaeralis* (Walker) *in Thailand*. IUFRO Regional Workshop on Pests and Diseases of Forest Plantations. 13 - 15 June 1988, Royal Forest Department, F/FRED Projectand FAO, Bangkok, Thailand.

Nair, K. S. S. (2007). *Tropical Forest Insect Pests*. Ecology, *Impact, and Management*. University Press, Cambridge, U.K.

Pérez Cordero, L. D. & Kanninen, M. (2003). Heartwood, sapwood and bark content, and wood basic density of young and mature teak (*Tectona grandis*) trees grown in Costa Rica. *Silva Fennica,* 37(1), 45-54.

Roychoudhury, N. & Mishra, R. K. (2021). Major insect pests of teak and their management-an update. *Pestology,* 45(7), 24-31.

Sakchowong, W. (1998). Effect of entomopathogenic fungi *Beaveria bassiana* (Balsamo) *Vuilemin* and *Metarhizium anisopliae* (Metchnikoff) Sorokin on teak defoliators (*Hyblaea puera* Cramer; Lepidoptera: Hyblaeidae). In *Proceedings of the IUFRO/FAO Workshop on Pest Management in Tropical Forest Plantations*, pp. 105-110. Chantaburi, Thailand.

Sudheendrakumar, V. V. (1986). Study on the natural enemies of teak pest, *Hyblaeapuera* and *Eutectonamachaeralis. KFRI Research Report* No.38 St. Joseph's I.S. Press, Trichur, India.

Sudheendrakumar, V. V., Mohamed A. M. I. & Mohanadas, K. (1988). Study on Bacteria pathogens associated with the teak defoliator, *Hyblaea puera* Cramer. In *Proceedings of the IUFRO/FAO Workshop on Pest Management in Tropical Forest Plantations*, pp. 1-4. Bangkok, Thailand.

Wiwatwitaya, D. (1996). Predatorants of teak bee-hole borer, *Xyleutes ceramicus* Walker (Lepidoptera: Cossidae). *Kasetsart Journal of Natural Sciences,* 30, 330-335.

Wiwatwitaya, D. (2000*). Insect Pest of Forest and Shed Tree in Thailand*. Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok, Thailand. (in Thai)

Chapter 13: Indonesia's Teak Resources, Breeding and Biotechnology

Anto Rimbawanto and ILG Nurtjahjaningsih

Abstract

Teak occurs naturally in India, Myanmar, Lao and Thailand, and has naturalized in Java where it was most likely planted around the seventh century and now covers more than 1.5 million ha across Indonesia. Teak genetic structure studies in Java suggest a narrow genetic base that is likely to have originated in southeast Asia. With growing interest in planting teak genetically improved seeds or clones are now available in Indonesia under the brand names of Super teak, Superior teak, Golden teak, JUN (Nusantara superior teak), JPP (Perhutani Plus teak), and Jumbo teak etc. The JUN clone has attracted particular attention from farmers as it can be harvested after 6-8 years even though wood quality is inferior to fully mature teak. DNA markers are rapidly being developed and applied for the genetic study of teak, such as genetic conservation of teak, and genetic improvement. The same technology can also be used to verify the legality of the timber.

Introduction

Teak (*Tectona grandis*) is renowned for its wood qualities such as medium strength and lightness with durability, dimensional stability, and resistant to termite and fungus, antioxidant and hydrophobic properties (FAO, 2009). Teak has existed in Indonesia since hundreds of years ago. Because of its long history, teak is often considered a native species to Java although recent scientific evidence proved it otherwise (Pandey & Brown, 2000; Verhagen & Fofana, 2010). Teak occurs naturally in India, Myanmar, Lao PDR and Thailand, and it is naturalized in Java, Indonesia, where it was most likely planted around the seventh century, and in Muna Island, Southeast Sulawesi around the sixteenth century (FAO, 2009). Since teak wood supply from old-growth and high-quality stands have already depleted, there has been a growing interest in establishing teak plantations. Plantations have been established in Asia, as well as in Africa, Latin America, the Caribbean and in the Pacific region (Pandey & Brown, 2000).

Photo 13-1 Remnant of century-old teak at Napabalano Nature Reserve in Muna, Southeast Sulawesi (Credit: A. Rimbawanto)

Since teak is not native to Indonesia, there has never been any wild growth teak. Teak from Java is considered comparable to natural teak from Myanmar because it was harvested from well matured plantations (over 100 years old trees). However, in the last 25 years, teak from well-matured plantations have disappeared due to excessive logging and replaced by teak from much younger resources. Subsequently, demand for teak is fulfilled by younger trees from recently established plantations.

Perhutani, a state-owned company, manages forest plantation on public land in Java, with a total area of around 3 million hectares, of which around 1.0 million hectares is teak. This plantation is also an important source of income, especially in the densely populated island of Java. It is estimated that more than 500,000 people (including family members) depend on teak as a source of income (Perhutani, 1993). Harvests from teak plantations today support a rapidly expanding furniture industry and teakwood products are directed to export markets.

Since teak is a slow-growing species in later years, well-matured teak may be harvestable at 60 or more years, high productivity plantation is significant (Kjaer & Foster, 1996). Genetic improvement and appropriate silviculture treatments of teak are critical for the success of the teak plantation. Genetic improvement is dependent on a species' existing pool of genetic variation (Zobel & Talbert, 1984). This means that understanding genetic variation patterns is important for matching a well-adapted seed source to a suitable physiographic location.

Biotechnology such as tissue culture has had some impacts on teak. This technique has been used to propagate selected teak or ortet commercially (Gupta et al., 1980; Goh & Monteuuis, 2001; Chia, 2003). In recent years, teak has also benefited from the advance of molecular (DNA) techniques, that can support higher yield teak plantations and shorter rotations, improve wood quality, resistant to pest and disease, adaptability to changing environment, and support Forest Law Enforcement, Governance and Trade (FLEGT).

This chapter highlights the conditions of teak genetic resources in Indonesia, the breeding programs to improve plantation productivity, and the application of molecular techniques on teak.

Teak Resources in Indonesia

In Indonesia, teak plantations are found mostly in Java, covering over 1 million hectares of public and private land, and in Southeast Sulawesi, particularly in Konawe, Muna, and Buton. Total teak plantation in Indonesia is estimated at around 1.5 million hectares of various age classes. Over the last few decades, as community participation in planting teak is growing due to the increasing demand, teak is also being planted in other parts of Indonesia such as in Sumatera, Bali, West Nusa Tenggara, East Nusa Tenggara, Kalimantan, and Sulawesi. These plantations form the backbone of Indonesia's teak-based furniture business.

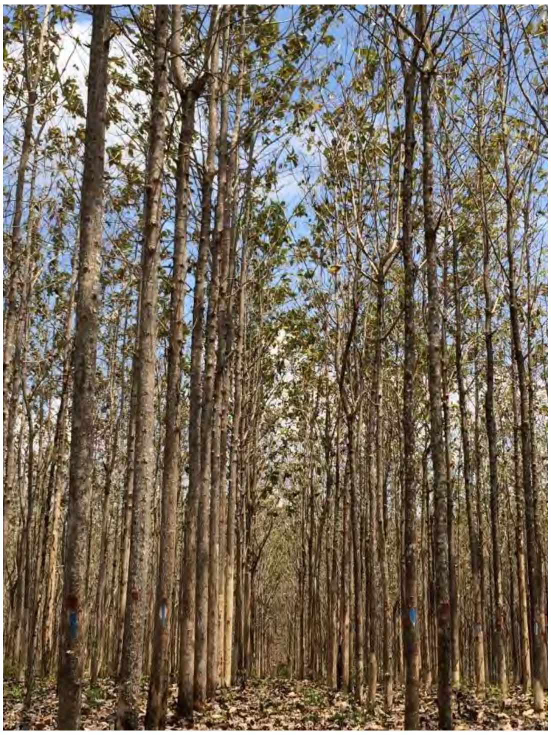


Photo 13-2 Clonal plantation of Jati Unggul Nusantara (JUN) 8-years old at Gunung Kidul Yogyakarta (Credit: A. Rimbawanto)

Contrary to the popular view of the strong relation between teak in Java with Indian origin, a recent study found that Indonesian teak plantations are mostly linked genetically to those from Laos, Thailand, and Myanmar (Prasetyo et al., 2020). The study revealed genetic structure of teak plantations across regions is weak, implying that most plantations were started using plant resources from a particular part of the natural population.

To maximize the potential yield and quality of logs, teak plantation requires integration of silviculture management (including site selection, site preparation, quality of planting stock, and the germplasm used) during establishment and subsequent maintenance and protection of the plantation. In Java, teak grows well on several soil types, including lime and marl formation as well as volcanic and alluvial soils (Beekman, 1949). Good soil drainage is also important for optimum growth. Good quality teak comes from an area with a distinct difference between dry and wet seasons, with optimum temperature between 22-27 ºC and annual rainfall between 1250-3750 mm (Perhutani, 1993).

Teak is one of the popular species planted by smallholder farmers. Teak seedlings with various brands, such as super teak, superior teak, golden teak, JUN (Nusantara superior teak), JPP (Perhutani's teak plus), and Jumbo teak, are available in response to the growing interest in teak planting. JUN clone has attracted attention from farmers as it can be harvested after 6-8 years. Even though the wood quality is inferior to fully matured teak (some say over 80 years), it fills a supply-demand gap for the local furniture sector.

In the southeast Sulawesi islands of Muna and Buton, teak has also become naturalized. However, it's also debatable where this teak came from. The historical record shows that teak has been in Buton since 17th century. A 21 m flagpole made of teak in the Sultanate of Buton Palace in Bau Bau is believed to have been erected in 1712 by Sultan Saikuddin Darul Alam. The flagpole is still standing up till now and amongst popular tourist attractions in the Sultanate fortress.

Photo 13-3 Flagpole made of teak more than 300 years old and the background board (Credit: A. Rimbawanto)

The accompanying board describes the background of the flagpole, which say "*Founded during the Sultan Sakiuddin Darul Alam's rule in the 17th century. The Sultanate of Buton's flag will be flown from this mast. The flagpole is made of teak wood and stands 21 meters tall. During Sultan Muhammad Isa Kaimuddin's rule in the 1870s, the flagpole was struck by lightning and damaged. The flagpole was repaired and is still standing strong today*".

Photo 13-4 Teak stand at Bau Bau, Buton Island (Credit: A. Rimbawanto)

Genetic Improvement

Genetic improvement refers to the application of forest genetics principles within a given silvicultural system to improve the genetic quality of the forest. Its purpose is to improve the genetic value of the population while maintaining genetic diversity (Zobel & Talbert, 1984). In intensely managed plantations, the use of genetically improved planting materials is crucial. Improved planting materials will not only ensure high productivity, but it can also reduce the risk of pest and disease infestation.

Natural teak populations have several attributes that influence their economic, ecological, and environmental values. Natural distribution across a wide range of edaphic and climatic conditions has huge potential for capturing adaptive genetic variation for genetic improvement. Hence, any teak improvement program must have a pool of genetic diversity from different populations. Further research and characterisation of teak genetic variation in planted and natural populations are critical to ensure high-quality planting material for breeding and mass propagation from well-documented and reliable sources. Those aiming to maintain or benefit from plantation should strengthen genetic diversity since a highly varied population has a much better chance of containing the optimal combinations of alleles capable of surviving a new disease.

A study on genetic diversity of teak resources in Indonesia reported that genetic diversity among 30 populations of teak was moderate with *He* 0.184 and mean genetic distance between populations 0.441, and these populations were divided into 3 groups, firstly Burma (Myanmar), secondly Java, India, Indo-China, Thailand, and thirdly Southeast Sulawesi (Widyatmoko et al., 2013). Information on genetic relatedness in the population is important to avoid interbreeding between relatives, which can result in reduced plant growth.

Genetic studies using plant materials originated from international provenance trials established in the early 1970s (Keiding et al., 1986; Kjaer et al., 1996) have been conducted. Between 1973-1977, a total of 75 provenances were under test on over 50 sites in 16 countries (Keiding, 1978). Results from the first and second assessments of the individual trials suggest that different seed sources perform differently in different regions (Kjaer et al., 1996).

Teak genetic improvement in Indonesia initially began in early 1932, when the colonial rule implemented a provenance trial of 13 ecotypes/provenances of India (Malabar, Central province dan Godavari), Indo China (Hinh, Kay, Kuoai, dan Kouoc), Muna Sulawesi and Java (Cepu, Pati, Ponorogo, Gundih, Kesamben), and 3 varieties in 3 different areas in Java. Assessment in 1958 reported that teak originated from Malabar and Java (Pati, Cepu and Ponorogo) are well adapted to the growing sites (Daryadi, 1959).

In the 1980s a major tree improvement program for teak was initiated following a collection of genetic materials from over 600 parent trees selected from well-matured plantations in Java and other islands. These genetic materials become the basis to establish progeny trials, clonal banks, and clonal seed orchards of the species. The first open-pollinated progeny trial was established in 1997. Subsequently, infusion of new materials from outside of Java was carried out to increase the genetic pool. Nowadays, genetically improved seeds or clones are available to the public.

The published data on teak productivity ranges from 5 to 10 m^3/ha/year under long rotation (up to 60 years) and 10 to 20

m^3/ha/year under short rotation (up to 20 years), with a productivity of 0.03 m^3/tree/year in a suitable condition (Cheliah et al., 2021). In Java, the productivity of selected clones is between 0.028 to 0.043 m^3/tree/year (Adinugraha & Pujiono, 2014). A trial in west Java of JUN clone (Nusantara superior teak) shows MAI of 0.039 m^3/tree/year (Supriono & Setianingsih, 2012).

Application of DNA Techniques

DNA markers have progressed at a phenomenal pace over the last four decades, owing to advancements in molecular biology technology, particularly since the invention of the PCR (Polymerase Chain Reaction) instrument in 1983. RAPD (Random Amplified Polymorphic DNA) (Williams et al., 1990) is the first PCR-based marker to be developed and widely used for agricultural, horticultural and forest crops. Other markers that are sequence variation based include AFLP (Amplified Fragment Length Polymorphism) (Voss et al., 1995) which is a combination of RFLP and RAPD, and SCAR (Sequence Characterized Amplified Region) (Watanabe et al., 2004; Widyatmoko & Shiraishi, 2019), minisatellites, and microsatellites (Fofana et al., 2009).

DNA markers are rapidly being developed and applied for the genetic study of teak. Genetic conservation of teak, as well as genetic improvement, can benefit from the advancement of DNA technology. Understanding genetic diversity in the natural populations is critical for conservation work. Other studies used a variety of molecular markers, including AFLPs (Vaishnaw et al., 2014; Minn et al., 2016), Inter Simple Sequence Repeats (ISSR) (Ansari et al., 2012), and microsatellite markers (Hansen et al., 2015; Win et al., 2015) to examine the population genetic structure and genetic variation of teak.

Win et al. (2015) reported a study on the genetic diversity of the teak natural population in Myanmar using microsatellite markers, which found that when compared to other native origins, teak populations from Myanmar have the highest genetic diversity, allelic richness, and moderate genetic divergence. Myanmar teak genetic resources should be prioritized for *in situ* conservation efforts. More recently, a genetic study of teak in a plantation in Java using single-nucleotide polymorphism (SNP) markers was reported by Prasetyo et al. (2020), which found that the Indonesian plantations had less genetic diversity compared to provenances of India, Myanmar, Thailand, and Laos. Furthermore, since the plantations in Java have a weak genetic structure across regions, it was concluded that plant materials from a single part of the natural teak distribution were used to establish most of the plantations.

Hansen et al. (2015) using neutral DNA markers, investigated the genetic diversity and differentiation of teak provenances across their natural distribution range. Most genetic diversity was found in provenances from India's semi-moist east coast, while the lowest was found in provenances from Laos. The further east the provenance was located, the less genetic variation there was in the eastern part of the natural distribution range, which comprised Myanmar, Thailand, and Laos. Overall, the distribution of genetic diversity supports the theory that teak originated in India and drifted eastward from there. Vaishnaw et al. (2014) revealed two distinct centres of teak diversity, namely central India, and Peninsular India.

Watanabe et al. (2004) reported the use of RAPD analysis to discriminate among teak plus tree clones and to improve the management of teak clones in Java. Clonal identification is important to ensure the identity of the clone, more importantly for clones used in a breeding program.

For tree improvement, three major areas have always been important for molecular marker applications: (a) the determination of genetic diversity within, between and among populations; (b) verification and characterization of genotypes; and (c) marker–assisted selection (MAS) (Haines, 1994; Krutovsky & Neale, 2005). Using microsatellite markers, Alcantara & Veasey (2013) reported the genetic diversity of teak genotypes used in Brazilian plantations.

Using a combined Next Generation Sequencing technique on the Illumina MiSeq system with genotyping on the Agena MassARRAY iPLEXTM platform, novel single nucleotide polymorphism (SNIP) loci for teak (*Tectona grandis* Linn. f.) were detected (Dunker et al., 2019). A total of 156 SNP markers has been detected that is suitable for population genetic studies of the species. For cost-effective genotyping a subset of 142 of these SNPs have been multiplexed into three groups.

Cross-fertilization is the primary mode of reproduction for this species. The outcrossing rate in different teak populations was between 89 and 95 percent by Kjaer et al. (1996). Using RAPD, Changtragoon & Szmidt (2001) found similar outcrossing rates (82 percent to 97 percent) in Thai teak populations. The outcrossing reproductive system seen in teak allows for significant amounts of genetic variation within teak populations, given that outcrossing encourages recombination.

DNA markers are also being used to support timber legality, such as distinguishing species, the population of a species and individuals of the same species (Dormontt et al., 2015). Teak timber was verified via a supply chain within Perhutani at Cepu using a DNA chain of custody method. These findings demonstrate that while paperwork may not always precisely reflect timber origins to specific trees, larger genetic provenance testing methods indicate valid timber origins from the specified plantation location (Dormontt & Lowe, 2019).

In another attempt to understand the genetic structure of naturalized and plantation stands in Indonesia, Nurtjahjaningsih et al. (2021) sampled leaf material for DNA analysis from landrace populations at Konawe, Muna, Buton, and one plantation at Gunung Kidul Java. Genetic structure analysis revealed that Java and Southeast Sulawesi were composed of different genetic structures, while teak at Southeast Sulawesi has a similar genetic structure.

Conclusion

In the tropics, teak has been and will continue to be a popular timber species for high value wood products. The durable wood fetches high price in the timber market remains the major factor that attract people to plant this species. Teak plantation in Indonesia, with a long history of teak cultivation will continue to expand particularly in smallholder plantations. Its rich genetic resources are important for further improving the genetic quality of the species. Smallholder farmers should be able to access the improved genetic material of teak so that the productivity of their plantations and the quality of the timber can be improved, which eventually will increase their income. Advanced technology such as DNA markers is now available to accelerate the genetic improvement of teak. The same technology can also be used to verify the legality of the timber.

References

Adinugraha, H & Pujiono, S. (2014). Growth evaluation of teak clonal test plantation at 10 years old in Wonogiri, Central Java. *Jurnal Hutan Tropis*, 2(2). (in Indonesian)

Alcantara, B. K. & Veasey. E. A. (2013). Genetic diversity of teak (*Tectona grandis* L.F.) from different provenances using microsatellite markers. *Rev. Árvore*, 37(4), 747-758. DOI: 10.1590/S0100-67622013000400018.

Ansari, S. A., Narayanan, C., Wali, S. A., Kumar, R., Shukla, N. & Rahangdale, S. K. (2012). ISSR markers for analysis of molecular diversity and genetic structure of Indian teak (*Tectona grandis* L.f.) populations. *Ann. For. Res,* 55(1), 11-23.

Beekman, H. A. J. M. (1949). Houtteelt in Indonesia (Silviculture in Indonesia). H. Veenam and Zonen, Wageningen.

Changtragoon, S. & Szmidt. A. E. (2001). Genetic diversity of teak (*Tectona grandis* L.f.) in Thailand revealed by Random Amplified Polymorphic DNA (RAPD) markers. In *IUFRO Working Party 2.08.01 Troplical Species Breeding and Genetic Resources: Forest Genetics for the Next Millennium*. 8-13 October 2000, p. 82-83. International Conferences Centre, Durban, South Africa.

Chelliah, B., Ravi, A. & Muthurasu, N. (2021). Modern silvicultural practices and productivity of Teak. In *The Teak Genome. Compendium of Plant Genomes*. (eds Y. Ramasamy, E. Galeano & T. T. Win), Springer, Cham. https://doi.org/10.1007/978-3-030-79311-1_3

Chia, F. R. (2003). Field performance of tissue culture-derived teak (*Tectona grandis*). *Journal of Tropical Forest Science,* 15(3), 493-496.

Daryadi, L. (1959). Penyelidikan seleksi jati (*Tectona grandis*), Pengumuman No.70 Lembaga Penelitian Hutan, Bogor.

Dormont, E. E. & Lowe, A. (2019). *Developing DNA-based Chain of Custody Systems for Legally Sourced Teak*. ACIAR Final Report Project FST/2016/025, Canberra, Australia.

Dormontt, E. E., Boner. B., Braun, B., Breulmann, G., Degen, B., Espinoza, E. et al. (2015). Forensic timber identification: It's time to integrate disciplines to combat illegal logging. *Biological Conservation,* 191, 790-798. DOI: 10.1016/j.biocon.2015.06.038.

Dunker, B, Dormontt, E. E., van Dijk, K., Dixon, R. M., Jardine, D.I., Kireta, D. et al. (2019). A set of 156 SNP markers for teak (*Tectona grandis* Linn. f.). *Conservation Genetics Resources*, 12, 205-207. DOI 10.1007/s12686-019-01099-7.

FAO. (2009). *The Future of Teak and the High-Grade Tropical Hardwood Sector*. Planted Forests and Trees Working Paper FP/44E. http://www.fao.org/docrep/012/k6549e/k6549e00.pdf

Fofana, I. J., Ofori, D., Poitel, M. & Verhaegen, D. (2009). Diversity and genetic structure of teak (*Tectona grandis* L. f.) in its natural range using DNA microsatellite markers. *New Forests,* 37(2),175-195.

Goh, D. & Monteuuis, O. (2001). Production of tissue-cultured teak: the Plant Biotechnology Laboratory experience. In*: Proceeding of the Third Regional Seminar on Teak: "Potential and opportunities in marketing and trade of plantation Teak: Challenge for the New Millenium*", pp/ 237-247. *31 July – 4 August 2000*, Yogyakarta, Indonesia.

Gupta, P. K., Nadgir A. L., Mascarenhas, A.F. & Jagannathan, V. (1980). Tissue culture of forest trees: Clonal multiplication of Tectona grandis L. (teak) by tissue culture. *Plant Science Letters,* 17(3), 259-268.

Haines, R. (1994). *Biotechnology in Forest Tree Improvement: With Special Reference to Developing Countries*. 1st ed. Italy: Food and Agriculture Organization of the United Nations, 230 p.

Hansen, O. K., Changtragoon, S., Ponoy, B., Kjær, E. D., Minn, Y., Finkeldey, R. et al. (2015). Genetic resources of teak (*Tectona grandis* Linn. f.) —strong genetic structure among natural populations. *Tree Genetics & Genomes,* 11, 802. DOI 10.1007/s11295-014-0802-5.

Keiding, H. (1978). Five-year progress report on international provenance trials of teak, *Tectona grandis* L.f. In: *Proceed. Joint IUFRO Workshop on Progr. & Problems of Gen. Impr.Trop.For.Trees*. Vol. II. CFI Oxford.

Keiding, H., Wellendorf, H. & Lauridsen, E. B. (1986). *Evaluation of an International Series of Teak Provenance Trials*. Danida Forest Seed Centre, Humlebaek, Denmark

Kjaer, E. D. & Foster, G. S. (1996). *The Economics of Tree Improvement of Teak* (Tectona grandis) *Technical Note 43*. Danida Forest Seed Centre, Humlebaek, Denmark.

Kjaer, E. D., Seigismund, H. R. & Suangtho, V. (1996). A multivariate study on genetic variation in teak (*Tectona grandis*). *Silvae Genetics,* 45(5-6), 361-368.

Krutovsky, K. V. & Neale, D. B. (2005). Nucleotide diversity and linkage disequilibrium in cold-hardiness- and quality-related candidate genes in Douglas fir. *Genetics,* 171, 2029–2041.

Minn, Y., Gailing, O. & Finkeldey, R. (2016). Genetic diversity and structure of teak (*Tectona grandis* L.f.) and dahat (*Tectona hamiltoniana* Wall.) based on chloroplast microsatellites and Amplified Fragment Length Polymorphism markers. *Genetic Resources and Crop Evolution*, 63(6), 961-974.

Nurtjahjaningsih, I. L. G., Rimbawanto, A., Fauzi, A., Dormontt, E. E. & Low, A. J. (2021). Genetic structure of teak from Southeast Sulawesi Indonesia based on microsatellite markers. (*In preparation*).

Pandey, D. & Brown, C. (2000). Teak a global overview. *Unasylva,* 51(201), 3-13.

Perhutani, P. (1993). Teak in Indonesia. In: *FAO., 1993. Teak in Asia. Forestry Research Support Programme for Asia and the Pacific*. Food and Agriculture Organization of the United Nations, Bangkok.

Prasetyo, E., Widiyatno, W., Indrioko, S., Na'iem, M., Matsui, T., Matsuo, A., Suyama, Y. & Tsumura, Y. (2020). Genetic diversity and the origin of commercial plantation of Indonesian teak on Java Island. *Tree Genetics & Genomes,* 16(2). DOI: 10.1007/s11295-020-1427-5.

Supriono, B. & Setyaningsih, L. (2012). Growth of Superior Teak Plant Nusantara with Agroforestry Pattern at Five Years Old. *Jurnal Sains Natural,* 2(2), 179 - 185

Vaishnaw, V., Mohammad, N., Wali, S.A., Kumar, R., Tripathi, S.B., Negi, M.S. et al. (2014). AFLP markers for analysis of genetic diversity and structure of teak (*Tectona grandis*) in India. *Canadian Journal of Forest Research*. DOI 10.1139/cjfr-2014-0279.

Verhagen, D. & Fofana, I. J. (2010). What is the genetic origin of teak (*Tectona grandis* L.,) introduces in Africa and in Indonesia. *Tree Genetics & Genomes, 6,* 717-733.

Vos, P., Hogers, R., Bleeker, M., Reijans, M., van de Lee, T., Hornes, M. et al. (1995). AFLP: a new technique for DNA fingerprinting. *Nucleic Acids Research,* 23(21), 4407-4414.

Watanabe, A., Widyatmoko, A., Rimbawanto, A. & Shiraishi, S. (2004). Discrimination of teak (*Tectona grandis*) plus trees using selected random amplified polymorphic DNA (RAPD) markers. *Journal of Tropical Forest Science,* 16(1), 17-24.

Widyatmoko, A. & Shiraishi, S. (2019). Development of SCAR markers for identification of teak clones. In: *AIP Conference Proceedings. International Conference on Biology and Applied Science (ICOBAS) (13–14 March 2019)*, pp. 030001-1 - 030001-7. Malang, Indonesia.

Widyatmoko, A., Rimbawanto, A. & Chasani, A. A. (2013). Genetic Relationship among Teak (*Tectona grandis*) Populations Based on RAPD (Random Amplified Polymorphic DNA) Markers (in Bahasa). *Jurnal Pemuliaan Tanaman Hutan*, 7(3),151-166.

Williams, J. G. K., Kubelik, A. R., Livak, K. J., Rafalski, J. A. & Tingey, S. V. (1990). DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic Acids Res.*, 18, 6531–6535.

Win, T. T., Watanabe, A., Goto, S. & Hirao, T. (2015). Genetic diversity of teak populations in native regions and plantations in Myanmar detected by microsatellite markers. *Bull. Univ. of Tokyo For,* 132, 1-15.

Zobel, B. & Talbert, J. (1984). *Applied forest tree improvement*. Wiley, New York.

Chapter 14: Effects of First Thinning on Growth and Stem Form of Teak Plantations in Thailand

Tosporn Vacharangkura

Abstract

The effects of first thinning on growth and stem form of teak stand were examined in Uttaradit Province, northern Thailand. In this study, a randomized complete block design with 3 replications was used and thinning from below (low thinning) was applied as the first thinning. The thinning treatments were as follows: removal of basal area at the level of 0% (control), 30% (light), and 50% (moderate). The measurement period after thinning was 4 years. The results of the study revealed that moderate thinning provided the largest mean basal area and mean stem volume of individual trees in the stands compared with the other treatments. The total stand volume increase in production per hectare was largest in light thinning plots and differed significantly from control plots, but no significant difference was noticed in moderate thinning plots. The light and moderate thinning intensities reduced the annual stand volume increment by 23% and 64%, respectively, related to the mean stand volume increment of thinned stands before thinning was executed, whereas those in control plots reduced by almost 99%.

Part of total stand volume production of control plots was lost through natural mortality. In the thinned plots, natural mortality was considerably low compared to the control plots. The mean diameter (DBH) increment of all trees as well as the mean DBH increment of the dominant trees was enhanced with increasing thinning intensity, but there was no significant difference among the thinned and control plots. However, the mean DBH increment of all trees in control plots was similar to those in light thinning plots. In contrast, total height increment of all trees and the dominant trees were not affected by thinning intensity. Live-crown ratio, slenderness ratio and absolute form factor of the trees in the stand were affected by different thinning intensities. Live-crown ratio increased with greater thinning intensity. On the other hand, slenderness ratio decreased with greater thinning intensity. The absolute form factor was smallest in control plots, and different thinning intensities had clear effects on the absolute form factor. Thus, thinning intensity resulted in improved growth and yield of stands after as well as individual tree size and tended to have positive effects on stem form.

Introduction

Control of stand density by thinning has been the major tool in regulating tree growth and improving timber quality. Although thinning from below may increase the merchantable volume of a stand, usually it does not increase the total volume increment per unit area (Hasenauer et al., 1997; Zeide, 2001). Many studies have revealed that the stand volume increment of various tree species does not decline with decreasing stand density (Hamilton, 1981; Horne et al., 1986). This indicated that thinning from below (or low thinning) redistributes the increment of individual trees from small trees to larger ones, and a smaller number of trees was able to produce the same volume increment per unit area.

Thinning practice also affects wood properties, such as heartwood proportion, wood density and stem form. Stem form is defined as the rate of taper of a stem. Taper is the decrease in diameter of a stem of a tree or of a log from base upwards. The potential change in stem form as a result of thinning is important with regard to volume and product recovery prediction. Most variation in stem form may be traced to the change in size and distribution of the live crown on the stem and to the length of the branch-free bole (Larson, 1963).

The objective of this study was to relate thinning intensity of the first thinning operation with diameter, height, volume increment and stem form on the basis of permanent long-term experiments with thinning from below (or low thinning) in teak plantation in Thailand. It is an opportunity for us to investigate total stem volume production, thinning removal as well as changes in stem form, during the whole rotation.

Materials and methods

Study site

The thinning trial was established in a private teak plantation at Tha Sao District, Mueang Sub-District, Uttaradit Province, on a site with a tropical monsoon climate, and mountainous region in northern Thailand. The mean annual temperature is approx. 27.7 °C with minor daily and annual fluctuations. The annual precipitation is 1,432.6 mm with six dry months. The study site was located at an altitude of 105 m a.s.l., at 17o 41’ 25.5” N, and 100o 17’52.8” E. In an area original cleared for agricultural crops, a 47 rai (7.52 ha) Tectona grandis plantation was established in May, 2005 with initial spacing of 2x4 m (1,250 tree ha-1). The first thinning was conducted in May, 2011 when the teak plantation was 6 years old. The pure teak stand presented canopy closure but severe competition was not evident. The stand basal area was around 1.90 m2rai-1 (11.88 m2ha-1). There was no other silvicultural interventions such as pruning applied to the plantation prior to thinning.

Experimental design and treatments

The experimental design consisted of randomized complete blocks, with three treatments and three replicates. Prior to thinning each treatment consisted of 200 trees. (Including dead trees) in square blocks of 1,600 m^2 (20x10 trees under a spacing of 2x4 m),

excluding the buffer zones consisting of two lines of trees, each of them thinned according to the corresponding treatment they were bordering. (Figure 14-1). Thinning from below or low thinning (defined as the thinning method that favors the tallest trees in the stand by removal the lower crown class) with different thinning intensities was applied to each treatment based on the percentage of the stand basal area prior to thinning. The trees removed in each treatment were also selected based on crown class, i.e., dominant, co-dominant, intermediate, and suppressed and also based on characteristics of tree, e.g., no defects, some defects, weak and standing dead. All trees in each thinned stand were divided into five classes and the trees in the fifth class (or the lowest class, i.e., consisting of weak trees, dead trees, and fallen trees) were selected before the others until the target basal area removal in each treatment was reached. The thinning treatments were removal of initial basal area at rate of 0% (unthinned or control), 30% (light) and 50% (moderate).

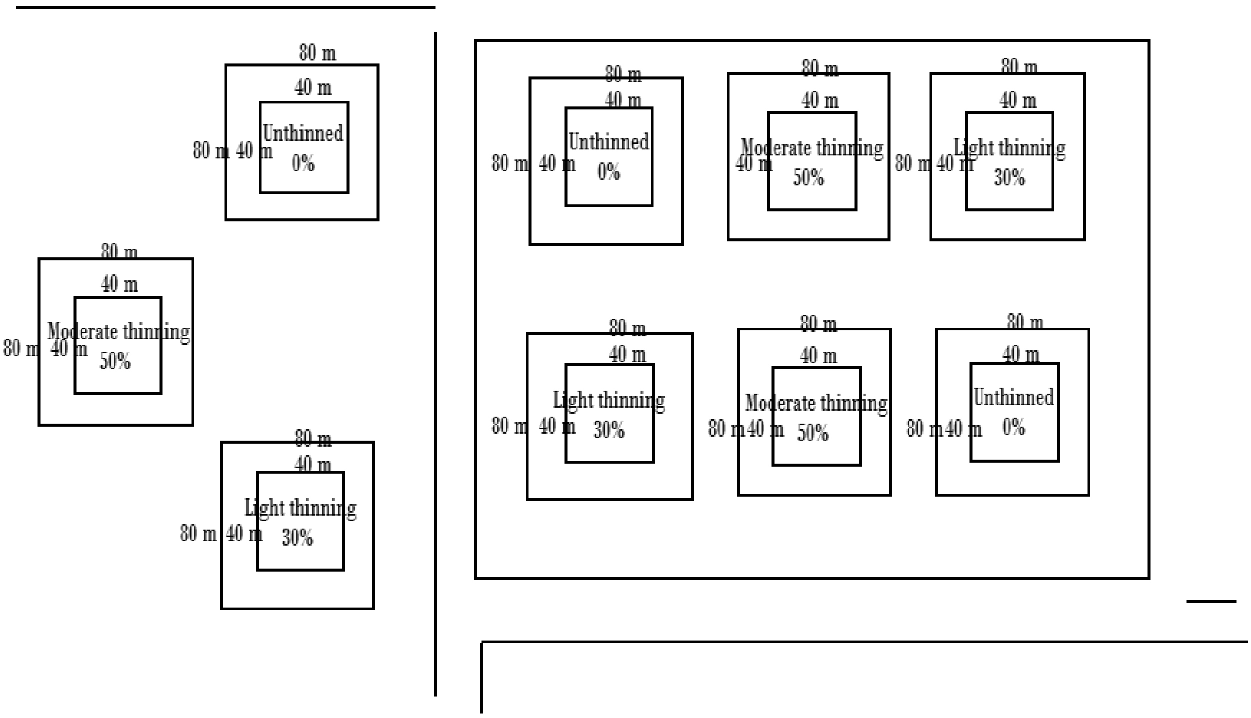


Figure 14-1 Layout of experimental plots

Measurements

Prior to thinning, the experimental plots were measured and re-measured again just after thinning was conducted. Following thinning the tree sizes were measured and surviving trees were surveyed in each plot every year. The measurement period was 4 years. At the time of the last measurement, stand age was 10 years. All living trees in each treatment were numbered and marked at breast height (1.37 m) for annual measurement of stem diameter at breast height (DBH), total height (H), and height to crown base (Hb), using a diameter tape and measuring pole. Digital hypsometer was used when total tree height was more than 15 m.

Two years after thinning, the stem diameter of 10 randomly-selected trees per treatment (control, light thinning and moderate thinning) was measured, using electronic BAF-scope/dendrometer (CRITERION RD 1000). The diameter of a standing tree at target points along the stem and total height of the tree were measured and recorded. The data was used to construct the allometric equation for calculating individual stem volume of trees in each treatment.

Basal area and volume were calculated for each tree and stand total basal area and total volume were calculated by summing the values of all trees in the measurement plot, and then these values were converted to one rai (1,600 m2 or 0.16 ha). The stem volume of each tree was calculated at the thinning time, just after thinning and 1 year after thinning from the stem volume equation for this species presented by Vacharangkura (2001):

V = 0.00009734 DBH1.99583 H0.64695

Where V is the over bark volume (m3), DBH is the diameter at breast height over bark (cm) and H is the tree total height (m).

Because thinning affected stem form (shape) of any tree in stands, different stem volume equations were calculated for each stand with different treatments. The nonlinear model used to calculate individual stem volume was:

V = a(DBH2H)b

Where a and b are constants. Mean basal area and mean stem volume of each treatment were calculated to examine tree size. Annual increment was calculated as the difference between successive measurements divided by the number of years between the measurements. Dominant trees were based on 100 trees by diameter (DBH) of the largest trees per hectare (16 trees per rai). Total volume production and stand volume increment were calculated to examine the effects of the thinning operation.

In order to evaluate the effect of thinning on stem form, the three parameters were applied to investigate the attributes of trees in each treatment at the time before and after thinning was performed. These parameters were:

(1) live-crown ratio (the ratio between crown height and total height (H-Hb)/H)
(2) slenderness ratio (the H/DBH ratio)
(3) absolute form factor (defined as the ratio of the volume of a tree or its part to the volume of a cylinder having the same length and cross section as the tree).

These parameters were calculated for each tree at the time before and after thinning, and then the average in each treatment was used to examine the effect of thinning on stem form.

Statistical analysis

The effects of thinning intensity on tree size, individual growth rate growth rate of stand and quality of stem form were analyzed. ANOVA was applied to examine statistical significant of the differences among treatment. The mean difference comparison, using Tukey HSD were performed to compare the means among treatments. In the tables and figures, the treatments marked with the same letter are not significantly different ($p > 0.05$).

Results

Effects of the thinning on tree size

ANOVA showed that there was no significant difference ($p \geq 0.05$) among treatments in terms of mean DBH, mean height, stand basal area, or stand volume. This means that the plantation had homogeneous structure even though there were slight differences in stand density in the moderate thinning plots compared with the light thinning and control plots (Table 14-1).

Just after thinning, mean DBH was not significantly different between thinned plots, but the thinned plots were different from the control plots. There was no significant difference among treatments in term of mean height. Stand basal area differed significantly in all treatments ($p \leq 0.05$). There was no significant difference in stand volume in the light thinning and moderate thinning plots, both the thinning type plots were significantly different from the control plots. The density of trees differed significantly because of the difference in thinning intensities (Table 14-1).

By the final measurement at 4-year after thinning, the differences in stand density among treatments had changed. There were no significant differences in stand density among treatments because mortality was high in the control plots owing to the severe competition between trees. Mean diameters of the residual stands increased significantly in thinned plots and differed significantly from control plots. On the other hand, there was no significant difference in mean height among treatments. Stand basal area was highest in the control plots (10.06 m2 ha-1) but was not significantly different from plots that had received light thinning. There was no significant difference in stand basal area in all thinned plots($p \geq 0.05$). Four years after thinning, stand volume had increased in all of the thinned plots but decreased in control plots. There was no significant difference in stand volume among the treatments (Table 14-1)

Table 14-1 Stand characteristics of Den Dan plantation before, just after and 4-year after thinning

Before thinning	**Treatment**		
	Light	**Moderate**	**Unthinned**
No. of trees (tree ha^{-1})	1219 (±1.00) a	1206 (±1.00) b	1225 (±0.58) a
Mean DBH (cm)	10.15 (±1.06) a	10.33 (±0.81) a	9.99 (±1.00 a
Mean Height (m)	10.94 (±1.31) a	11.01 (±1.00) a	10.44 (±1.44) a
Stand basal area (m ha^{-1})	11.88 (±0.30) a	12.06 (±0.23) a	11.15 (±0.30) a
Stand Volume (m^3 ha^{-1})	73.75 (±2.38) a	74.25 (±1.79) a	70.56 (±2.35) a
Just after thinning			
No. of trees (tree ha^{-1})	769 (±8.98) b	506 (±4.04) c	1225 (±0.58) a
Mean DBH (cm)	11.58 (±0.58) a	12.17 (±0.34) a	10.82 (±0.87 b
Mean Height (m)	12.45 (±0.48) a	12.54 (±0.24) a	11.17 (±1.32) a
Stand basal area (m ha^{-1})	8.31 (±0.21) b	5.94 (±0.12) c	11.75 (±0.28) a
Stand Volume (m^3 rai^{-1})	52.5 (±1.49) b	38.00 (±0.78) b	70.69 (±2.40) a
4-year after thinning			
No. of tree (tree ha^{-1})	750 (±11.01) a	494 (±6.11) a	1088 (±5.86) a
Mean DBH (cm)	13.16 (±0.70) b	14.50 (±018) a	12.49 (±0.45) b
Mean Height (m)	13.42 (±0.89) a	13.95 (±0.11) a	12.83 (±0.37) a
Stand basal area (m ha^{1})	8.75 (±0.26) ab	7.88 (±0.11) b	10.06 (±0.17) a
Stand Volume (m^3 ha^{-1})	88.69 (±3.28) a	55.69 (±0.72) a	63.44 (±1.01) a
Thinning ratio			
No. of tree (%)	36.91	58.20	0.00
Basal area (%)	30.32	50.77	0.00

Remarks: BA = basal area
Treatments marked with the different letters in row are significantly different (*p≤0.05*); standard deviation in parentheses

The corresponding basal area and stem volume development of trees in the stands at the time of thinning to 4 years after thinning are presented in Figure 14-2 and Figure 14-3 respectively. The mean basal area in moderate thinning plots was the larger year by year after thinning. At the age of 10 years (4-year after thinning) the mean basal area in moderate thinning plots differed significantly from those in light thinning plots and control plots. There was no significant difference in mean basal area between light thinned plots and control plots.

This result indicated that thinning promoted larger stem diameter in the stands and heavier thinning intensity tended to encourage larger stem diameter of trees. The corresponding mean stem volume of the stands was significantly different among treatments by 1-year after thinning. From 2-year after thinning, the mean stem volume in both light and moderate thinning plots were not significantly different, but were significantly different from the control plots. The results clearly demonstrated that thinning promoted larger tree size.

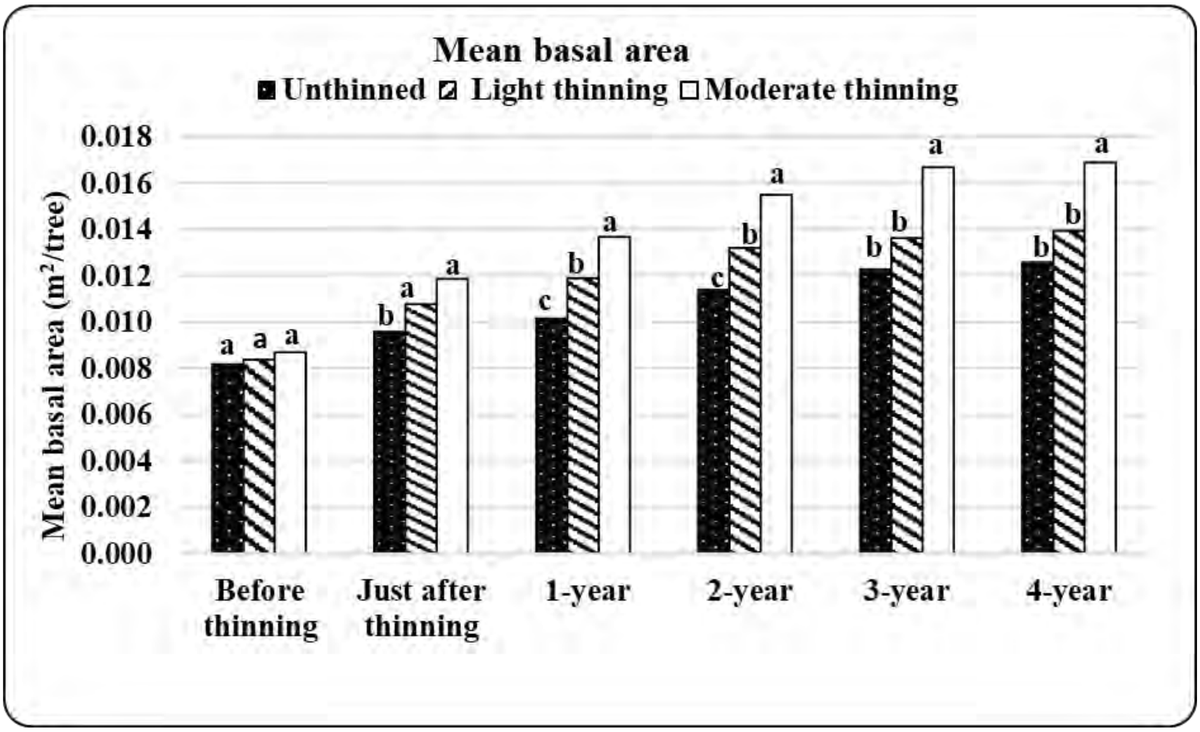


Figure 14-2 Mean basal area 4 years after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different. ($p \leq 0.05$)

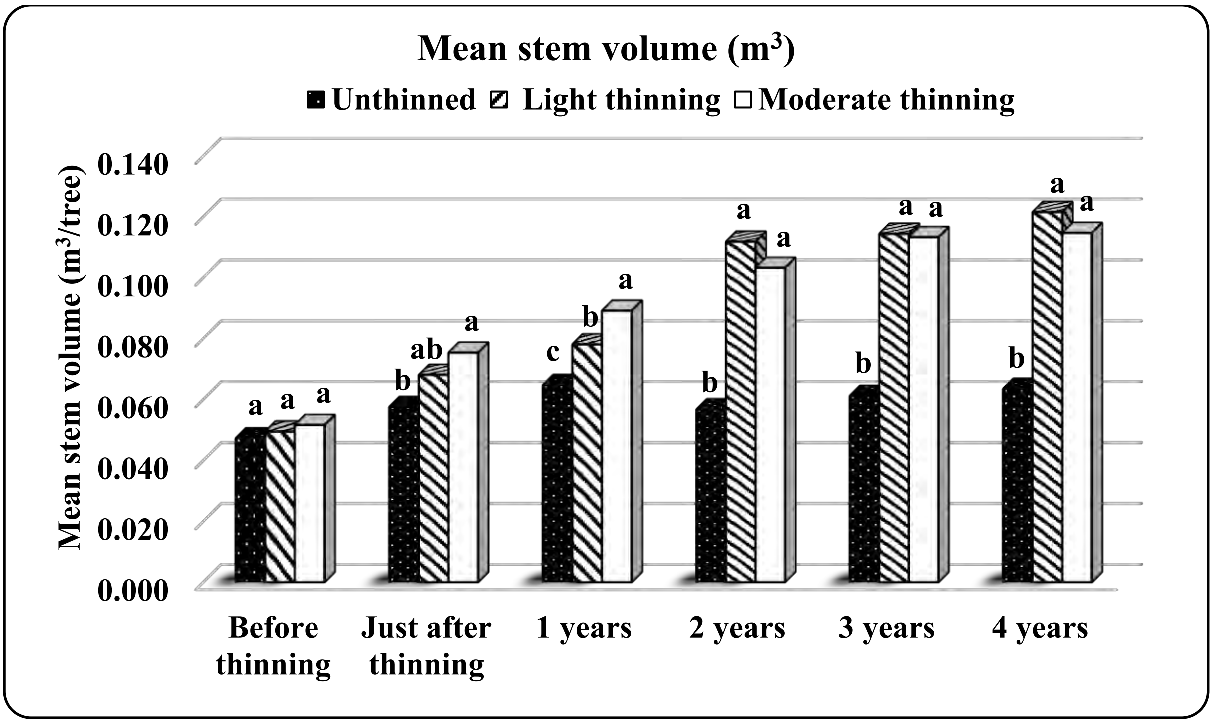


Figure 14-3 Mean stem volume 4-year after thinning. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different. ($p \leq 0.05$)

Effects of thinning on tree growth

The mean annual DBH increments of all trees in moderate thinning plots were the largest, followed by those in unthinned plots and light thinning plots (Figure 14-4). The differences among thinning intensities were not statistically significant in all treatments. The mean diameter increment was also calculated for the dominant trees (defined as 100 largest tree by DBH per hectare).

The mean annual increment of the dominant trees was the largest in moderate thinning plots, followed by those in light thinning plots and unthinned plots. The test of mean annual increment of the dominants revealed the same result as for all the trees. This result indicated that thinning intensity had no clear effect on annual DBH increment of the dominant trees in the residual stands (Figure 14-4).

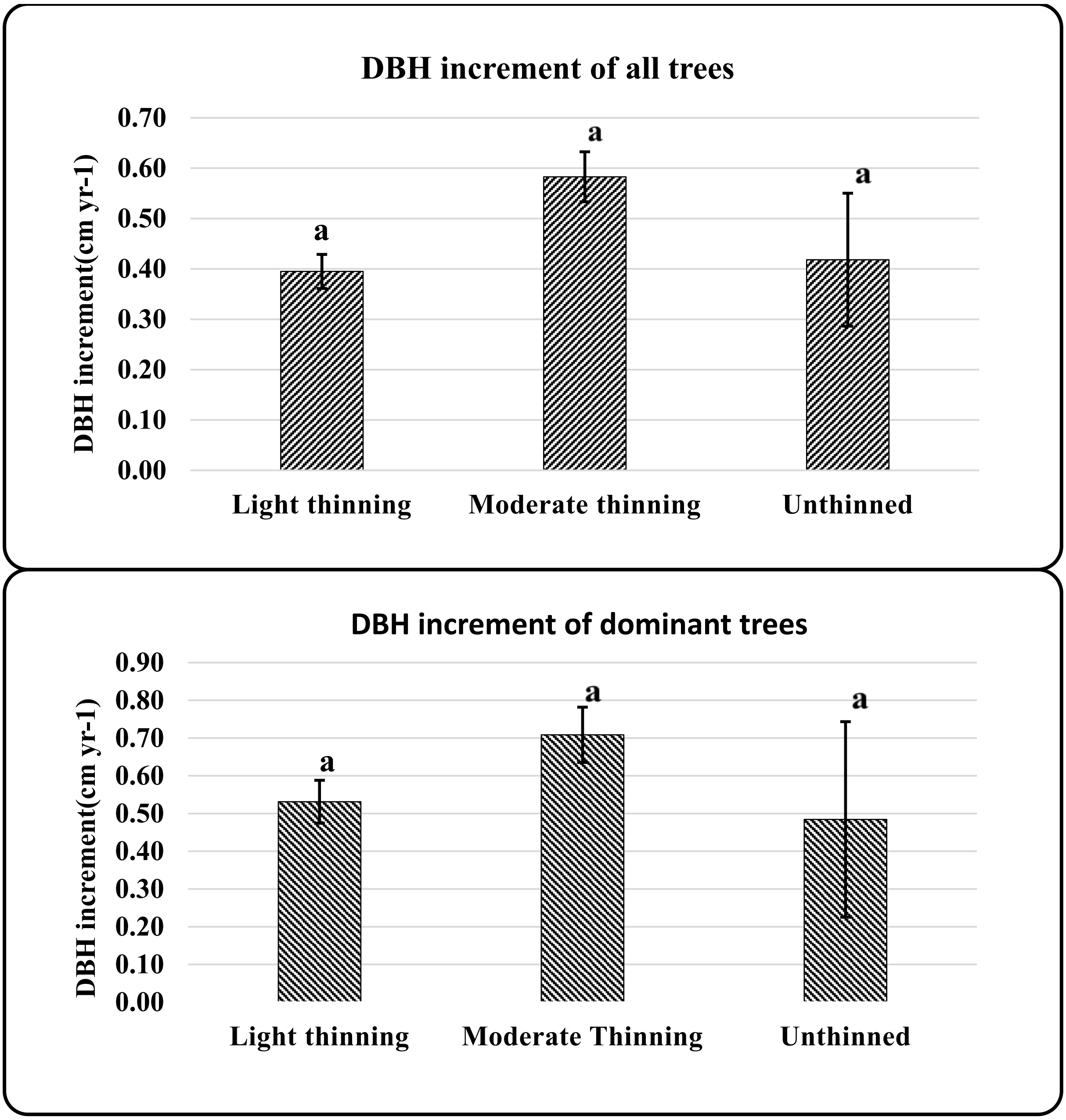
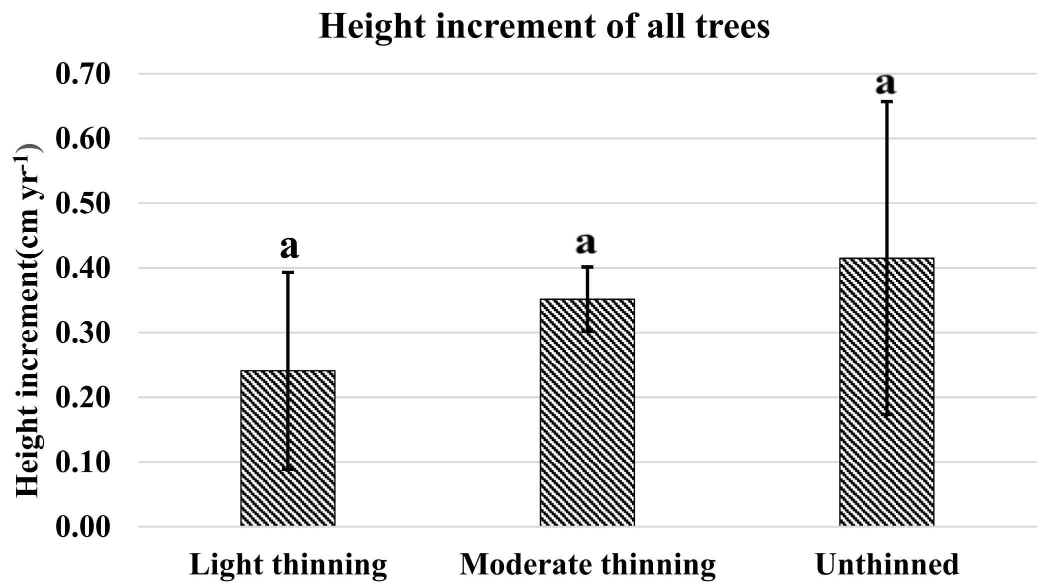


Figure 14-4 Mean annual DBH increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

In the case of mean height of all trees and mean annual height increment of the dominant trees, the results were aligned with the results in mean annual DBH increment presented above. The mean annual height increment of all trees and the dominant trees were the largest in the control plots, followed by the moderate thinning plots and then the light thinning plots. The heavier thinning plots seemed to show a greater annual height increment of all trees and the dominant trees, but there was no significant difference (Figure 14-5).



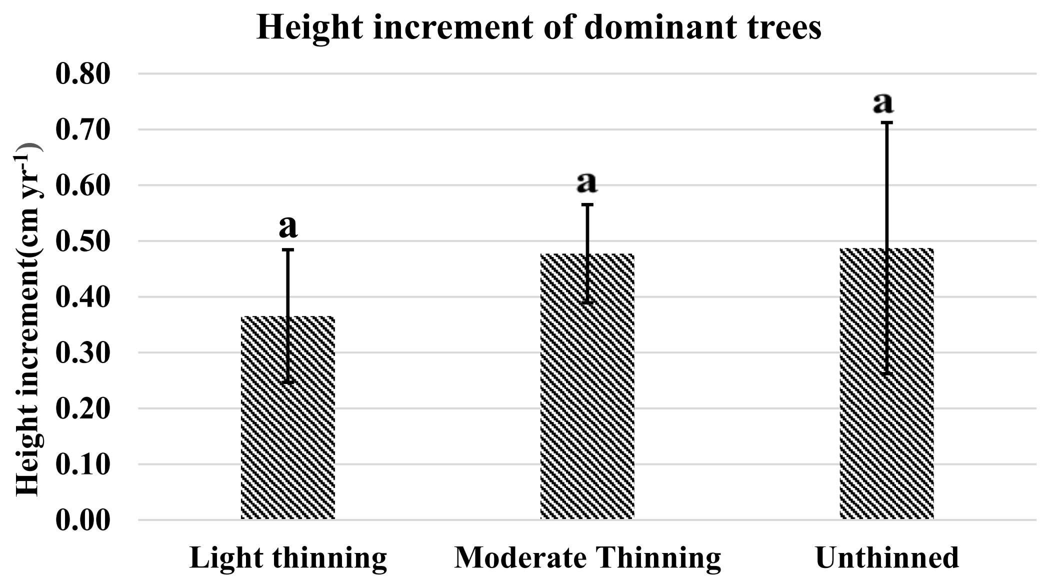


Figure 14-5 Mean annual height increment of all trees and dominant trees. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different ($p \leq 0.05$)

Effects of thinning on stand growth

The volume production of the residual stands calculated from the year of thinning was examined only in the fourth year after thinning, and the data are presented in Table 14-2. Total of volume production in each stand consisted of the volume of thinned trees, the volume of dead trees, and current volume production. The total volume production was the sum total of those three parts. The total volume of production in light thinning plots was the largest (112.16 m2 ha-1), followed by the moderate thinning plots and control plots. The number and volume of dead trees in control plots were much larger than those in both thinned plots, because of severe competition in control plots. The number and volume of dead trees was smallest in moderate thinning plots. This result may be caused the larger volume of production in moderate thinning plots than those in control plots. This result indicated that thinning prevented regular tree mortality.

Table 14-2 Stand volume production (m^3 ha^{-1}) in stands with different thinning intensities

Treatment	Volume of thinned trees	Volume of dead trees	Current volume production	Total volume production	No. of dead trees (tree)
Light	21.21	2.27	88.69	112.16	46
Moderate	36.77	0.94	55.71	93.42	19
Unthinned	0.00	7.85	63.47	71.32	227

The annual stand volume increment was larger in light thinning plots than those in moderate thinning plots, but there was no significant difference between the two thinning intensities. Compared with the control plots, the annual stand volume increment in light thinning plots differed significantly. In contrast, annual stand volume increment in moderate thinning plots was not significantly different from the control plots (Figure 14-6).

The total stand volume production was largest in light thinning plots, followed by moderate thinning and then control plots. The differences between the thinning intensities were not statistically significant. The total stand volume production in moderate thinning plots was not significantly different from that in the control plots (Figure 14-7). These results were in accordance with the results of annual stand volume increment.

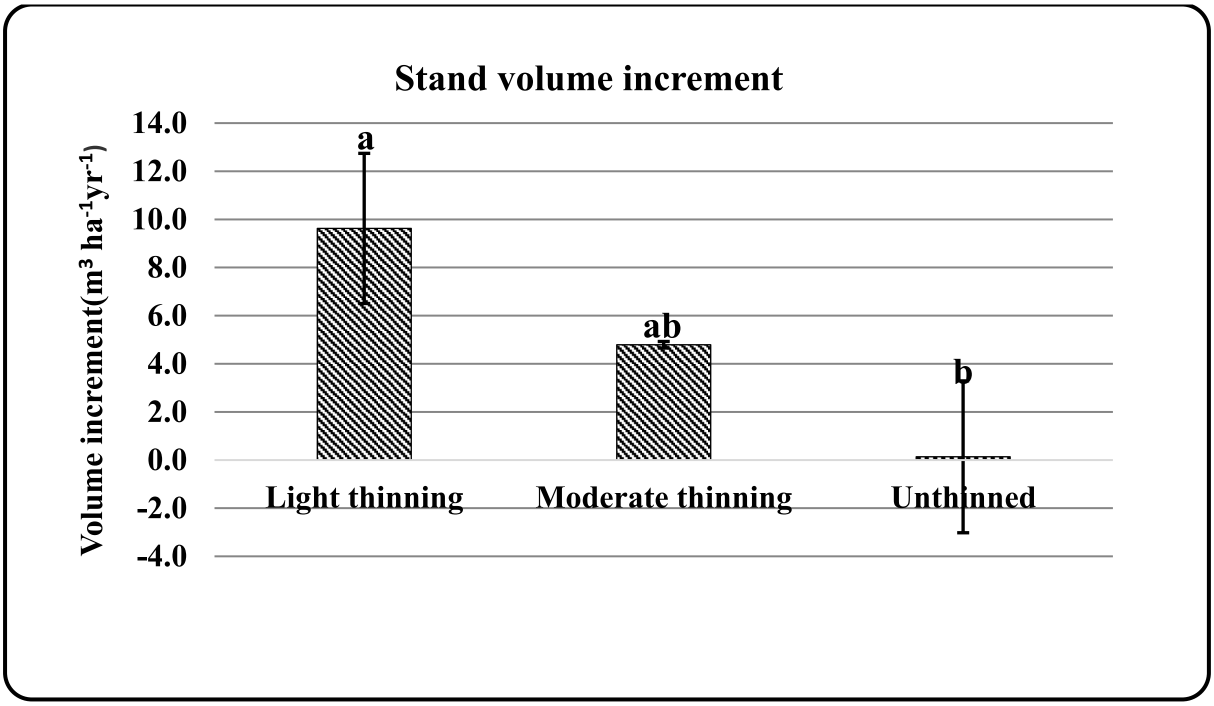


Figure 14-6 Mean stand volume increment. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different. ($p \leq 0.05$)

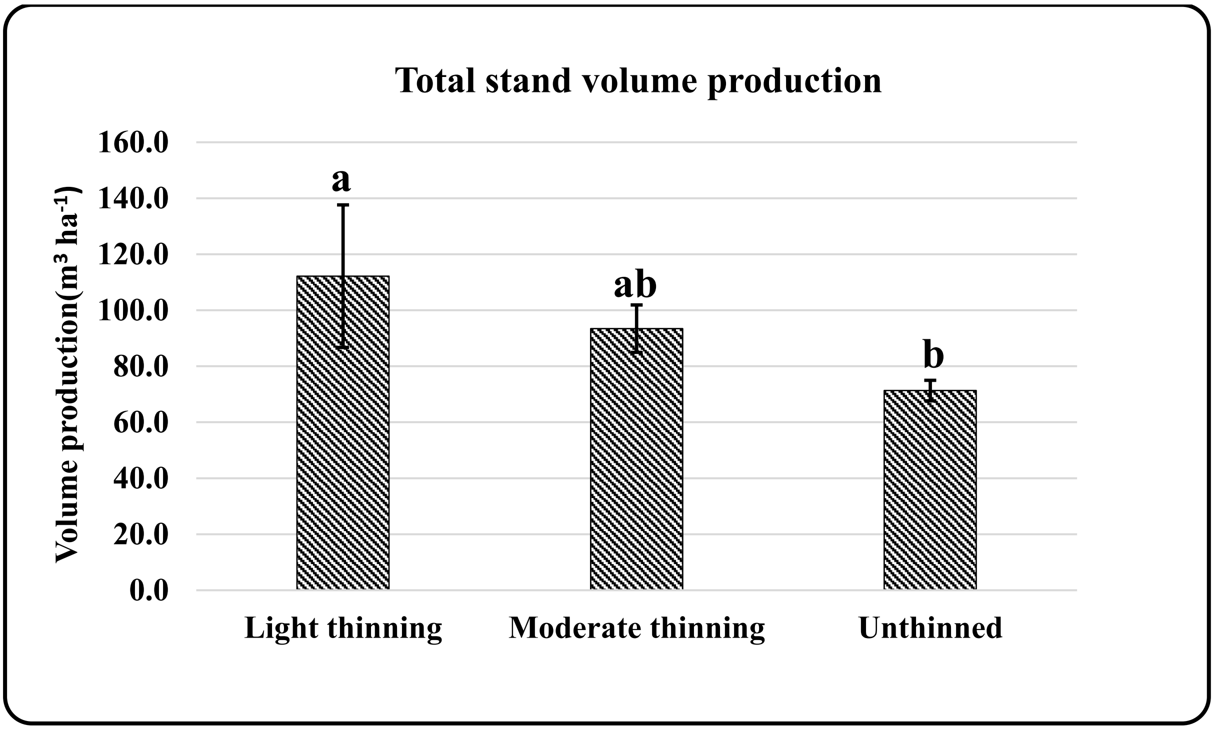


Figure 14-7 Total stand volume production. Letters signify individual statistical differences among treatments in each measurement time, based on the ANOVA. The treatments marked with the different letters are significantly different. ($p \leq 0.05$)

Annual stand volume increments on the thinned and control plots during the whole measurement period were also examined in relation to the mean volume increment of control plots (Table 14-3). As expected, annual stand volume increment decreased with increasing thinning intensities. This result was in accordance with the result of current volume production. The moderate thinning intensity decreased the annual stand volume increment by 64% compared with the mean volume increment of the control plots prior to thinning. The light thinning intensity decreased the annual stand volume increment by 23%, whereas control plots showed a decrease in annual stand volume increment of almost 99%.

Table 14-3 Decrease in annual stand volume increment

Treatment	Annual stand volume increment ($m^3ha^{-1}yr^{-1}$)		
	Just after thinning	**4 years after thinning**	**Decrease of annual volume increment (%)**
Light thinning	12.29	9.62	-22.51
Moderate thinning	12.38	4.79	-64.30
Unthinned	11.80	0.13	-98.86

Effects of thinning on stem form

The effect of thinning on live-crown ratio was observed from the year thinning was performed 4th year after thinning. The live-crown ratio in thinned stand was larger than those in control plots from 1-year after thinning. Among thinned plots the live-crown ratio in moderate thinning plots was larger than those in light thinning plots by 2-year after thinning and clearly differed from 3-year after thinning (Figure 14-8).

On the other hand, slenderness ratio (slenderness coefficient) in the control plots was larger than those in thinned plots from 1-year after thinning. The slenderness ratio in moderate thinning plots clearly showed lower values than those in the light thinning plots and control plots, although the differences between the moderate thinning and control plots were not clear (Figure 14-8).

Absolute form factor clearly differed among treatments from 3-year after thinning. The form factor in light thinning plots yielded more cylindrical trees than those in moderate thinning plots and control plots. The form factor of all thinned plots was larger than those of control plots (Figure 14-9).

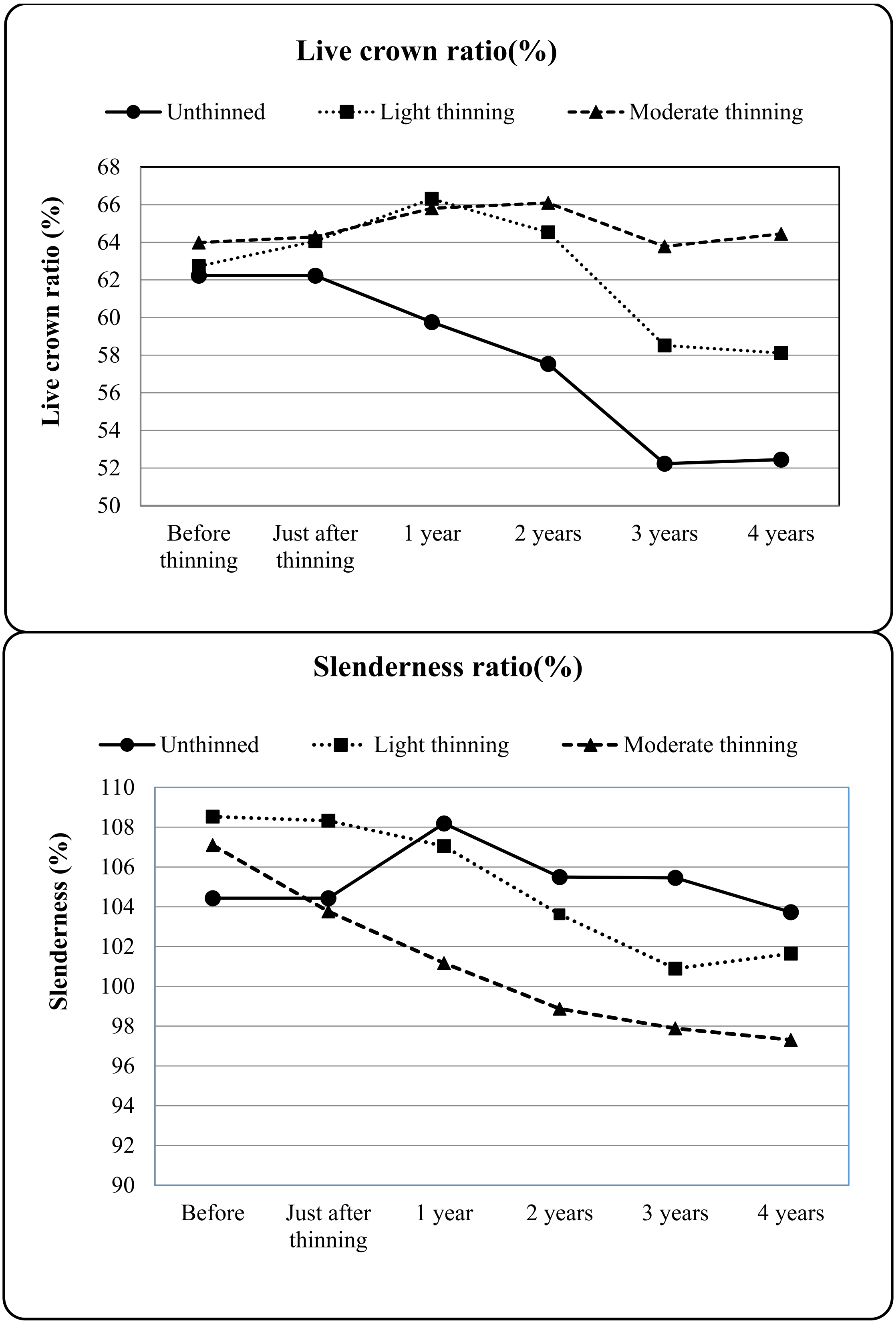


Figure 14-8 Live-crown ratio and slenderness before and after thinning

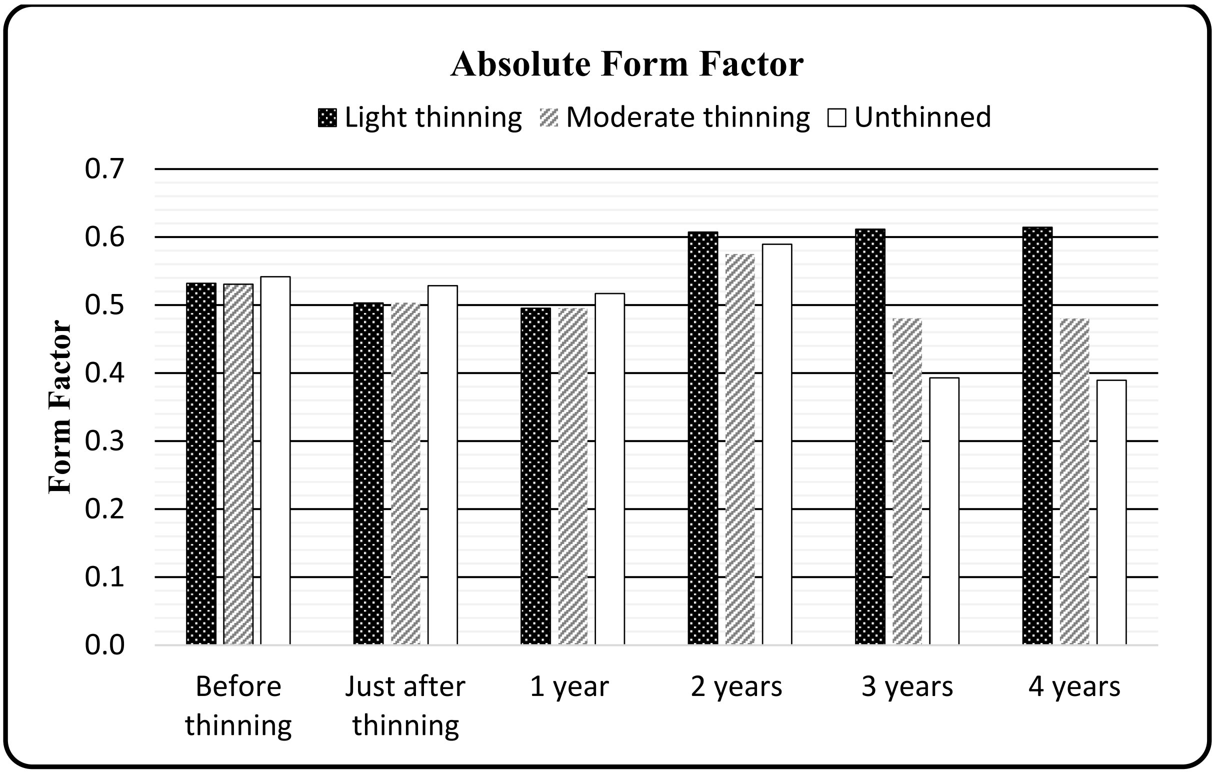


Figure 14-9 Absolute form factor before and after thinning

The effects of thinning on the three parameters contribute to the quality of stem form by 4-year after thinning, and the results are presented in Table 14-4.

The ANOVA results indicated that there were significant differences in live-crown ratio among treatments. The live-crown ratio in moderate thinning plots was larger than those in light thinning and control plots; however, there was no significant difference between moderate thinning plots and light thinning plots. Compared with the control plots, but the live-crown ratio in light thinning plots was not significantly different.

In contrast, the ANOVA results clearly indicated that there was no significant difference in slenderness ratio among the treatments. The slenderness ratio in moderate thinning plots was markedly different from the others because the value was less than 100%, whereas the corresponding values were higher than 100% in the other treatments.

As shown in Table 14-4, the absolute form factor in light thinning plots was the largest, followed by those in moderate thinning plots and control plots. The ANOVA results clearly showed that there were significant effects of thinning intensity on the absolute form factor.

Table 14-4 Parameters of tree attributes associated with quality of stem form: 4 years after thinning

Treatment	Live-crown ratio (%)			Slenderness ratio (%)			Absolute form factor		
Light thinning	58.11	(±3.96)	ab	101.65	(±3.56)	a	0.61	(±0.0200)	a
Moderate thinning	64.45	(±2.43)	a	97.31	(±1.91)	a	0.48	(±0.0005)	b
Unthinned	52.45	(±5.60)	b	103.73	(±1.71)	a	0.39	(±0.0050)	c

Treatments marked with the different letters are significantly different ($p \leq 0.05$); standard deviation in parentheses.

Discussion

The plantation responded to the first thinning, and the largest diameter increment occurred after moderate thinning (Figure 14-4). The results of this study were similar to the results of many other studies, especially in broad leaved stands (Hibbs et al., 1995; Rytter, 1995; Kerr, 1996; Clatterbuck, 2002; Meadows & Goelz, 2002). The increase in diameter growth in response to thinning was associated with an increase in photosynthetic rate and water and nitrogen use efficiency among thinned trees (Wang et al., 1995).

Height increment was not affected by thinning intensity in light or moderate thinning plots (Figure 14-5). Similar results were found in young stand of teak in Costa Rica after the first thinning was performed at 4 years (Kanninen et al., 2004). It is a well-known fact that the stand density has significant effects on diameter growth, but not on height growth, except for very high and very low stand densities. Our study results concurred with this finding.

The results clearly demonstrated that the remaining trees can rapidly occupy the growing space released by the thinned trees, especially in the light thinning plots. The DBH and height increment of all trees as well as that of the dominant trees clearly increased but there was no significant difference among thinned and control stands. The differences in diameter increment, basal area and volume in reaction to thinning can be explained by difference among tree species, site, stand age, tending practices, thinning type, and intensity (Hamilton, 1976). The results from our study support known information about the effects of thinning on stand production.

The total stand volume increment per unit area (per hectare) did not very much between the light thinning plots and moderate thinning plots, but there was significant difference from the control plots (Figure 14-7). The main reason was the dense control stands consumed more carbon for respiration than thinned stands; thus, net production will be reduced in dense stands (Savill et al., 1997). However, stand volume increment in the moderate thinning plots did not differ significantly from the control plots because a large number of trees were removed. The total stand volume production in the control plots was the smallest compared with the thinned plots (Table 14-2) because part of the total stand volume production was lost owing to severe competition in the stand. Therefore, thinning prevents natural mortality. The results in this study revealed that increasing thinning intensity resulted in only a small reduction in total stand volume production (from 112.16 m3ha-1 in light thinning plots to 93.42 m3ha-1 in moderate thinning plots) (Figure 14-7). However, the DBH increment of the remaining trees was clearly increased by thinning.

The results in this study revealed that thinning had a positive effect on stem form. Live-crown ratio in moderate thinning plots was largest and differed significantly from the control plots (Figure 14-8). It meant that moderate thinning expanded the crown size of the tree. Because we know that the crown contained the foliage which is the photosynthetic structure that provides carbohydrates for the growth and development of the whole tree (Larson, 1963; Leites & Robinson, 2004). The stem of a tree was strongly influence by its crown size and position (crown length, crown ratio and crown height). This result was confirmed in our study, whereby the mean stem volume of the individual tree in the control plots was the smallest compared with those in the thinned plots.

The slenderness ratios (or slenderness coefficients) of trees in the control plots were larger than those in the light thinning plots and moderate thinning plots, even though the difference among treatments was not statistically significant (Table 14-4). The slenderness ratio has been widely used as an index of the stability of trees, especially the resistance of a tree to windthrow. The preferred slenderness ratio of a tree was lower than 100%. In this study, the slenderness ratio was lower than 100% (97.31%) only in the moderate thinning plots. It meant that the trees in moderate thinning stands may be at low risk for windthrow compared with the others. However, for teak Pérez & Kanninen (2005) reported from their study in a young stand of a teak plantation in Costa Rica, intensive thinning had a positive effect on the stem form, inducing the development of tree with desired proportion of DBH and total height. Trees suffering high competition in the control and light thinning treatments will hardly reach the total height/DBH ratio (slenderness ratio) of 1:1. However, there have been no similar studies in teak plantations for comparison. The absolute stem form factor was largest in the light thinning plots and differed significantly from the moderate thinning plots and the control plots. The control plots had the smallest value (Table 14-4). The larger stem form factor provided a more cylindrical volume of a tree. The result of this study confirmed this; the mean stem volume of individual trees at 4 years after thinning in the light thinning plots was largest compared with the others. Pérez & Kanninen (2005) reported in young teak plantations in Costa Rica that moderate early thinning yielded more cylindrical trees (average form factor of 0.46) than late thinning and control (unthinned) (average form factor 0.43 and 0.44, respectively). The result of our study in the moderate thinning plots provided a similar value of stem form factor found in early moderate thinning stands from their study.

Conclusion

The moderate thinning intensity (50% based on basal area) applied at the age of 6 years gave the largest values in terms of mean DBH, mean height, mean basal area, and mean stem volume of the individual trees, whereas the control showed the smallest values. The total height was not statistically different among treatments, although the mean height in the control treatment was smaller than that of the other treatments. The current stand basal area and stand volume at 4 years after thinning was the largest with light thinning intensity, whereas those with the moderate thinning intensity were the smallest.

The results from this study indicated that the mean DBH increment of all trees, as well as the mean DBH of the dominant trees, increased with increasing intensity, but there was no significant difference among thinned and control stands. The mean DBH increment of all trees in the control stands was similar those in the light thinning stands. On the other hand, the height increment of all trees and of the dominant trees was not affected by thinning intensity. The mean stand volume increment produced per hectare was largest in the light thinning stands and differed significantly from the control stands, however, it did not differ significantly from the moderate thinning stands. In case total stand volume production at 4 years after thinning, the results was in accordance with the results of the mean stand volume increment.

The light and moderate thinning intensities reduced the stand volume increment by 23% and 64%, respectively, in relation to the mean stand volume increment of the control stands, whereas the stand volume increment in the control stand decreased by almost 99%. However, part of the total stand volume production of the control stands was lost because of natural mortality.

Thinning intensity had effects on tree (stem) attributes that contributed to quality of stem form. Live-crown ratio increased with increasing thinning intensity. On the other hand, slenderness ratio decreased with increasing thinning intensity. The absolute form factor was clearly affected by thinning intensity. The form factor was significantly different among treatments, and control stands gave the smallest form factor; therefore, thinning practice tended to have positive effect on stem form even in a young stand of teak.

References

Clatterbuck, W. K. (2002). Growth of a 30-year cherrybark oak plantation 6 years after thinning. In *Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference* (ed. K. W. Outcalt), pp. 189-192. USDA Forest Service. Gen. Tech.Rep, SRS-48, Asheville, North Carolina, USA.

Hamilton, G. J. (1976). Effects of line thinning on increment. *Forestry Commission Bulletin, 55*, 37-45.

Hamilton, G. J. (1981). The effects of high intensity thinning on yield. *Journal Forest, 54*, 1-15.

Hasenauer, H., Burkhart, H. E. & Amateis, R. L. (1997). Basal area Development in thinned and unthinned loblolly pine plantation. *Canadian Journal of Forest Research,* 27, 265-271.

Hibbs, D. E., Emmingham, W. H. & Bondi, M. C. (1995). Response of red alder to thinning. *Western J. Applied Forestry,* 10, 17-23.

Horne, R., Robinson, G. & Gwalter, J. (1986). Response increment: a method to analyze thinning response in even-aged forest. *Forest Science,* 32(1), 243-253.

Kanninen, M., Pérez, D., Montero, M. & Viquez, E. (2004). Intensity and timing of the first thinning of Tectona grandis plantations in Costa Rica: results of a thinning trial. *Forest Ecology and Management,* 203(1-3), 89-99.

Kerr, G. (1996). The effect of heavy on 'free growth' thinning on Oak (Quercus petraea and Q.robur). *Forestry,* 69, 303-317.

Larson, P. R. (1963). Stem form development of forest trees. *Forest Science Monograph,* 5, 1-42.

Leites, L. P. & Robinson, A. P. (2004). Improving taper equations of loblolly pine with crown dimensions in mixed-effects modelling framework. *Forest Science,* 50(2), 204-212.

Meadow, J. S. & Goelz, J. C. G. (2002). Fourth years effects of thinning on growth and epicormics branching in a red oak-sweetgum stand on a minor stream bottom site in west-central Alabama. In: *Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference* (ed K. W. Outcalt), pp 201-

208. USDA Forest Service, Gen Tech SRS-48, Asheville, North Carolina, USA.

Pérez, D. & Kanninen, M. (2005). Effect of thinning on stem form and wood characteristics of teak (*Tectona grandis*) in a humid tropical site in Costa Rica. *Silva Fennica,* 39(2), 217-225.

Rytter, L. (1995). Effects of thinning on the obtainable biomass, stand density, and tree diameters of intensity grown grey alder plantations. *Forest Ecology and Management,* 73, 135-143.

Savill, P., Evans, J., Auclair, D. & Falck, J. (1997). *Plantation Silviculture in Europe*. Oxford University Press, New York, USA.

Vacharangkura, T., Mungklarat, J., Kheannak, P., Wattanasuksakul, S., Nongnueang, S. & Krongkitsiri, V. (2001). *Growth and yield prediction of economic forest plantation*. Final Report Silvicultural Research Group. Forest Research and Development Bureau Royal Forest Department, Bangkok, Thailand. 61 p. (in Thai).

Wang, J. R., Simard, S. W. & Kimmins, J. P. (1995). Physiological responses of paper birch to thinning in British Columbia. *Forest Ecology and Management,* 73, 177-184.

Zeide, B. (2001). Thinning and growth: a full turnaround. *Journal Forest,* 99, 20-25.

Chapter 15: Silviculture Aspects of Large-Scale Teak Plantations in Brazil

Sylvio de Andrade Coutinho and Fausto Hissashi Takizawa

Abstract

Brazil has long been a world leader in eucalyptus and Pinus productivity with MAI of 35.7 and 30.5 m^3/ha/year, respectively. Teak trajectory in Brazil in recent years has also tended to follow the same path of these two species after the adoption of clonal technology for raising teak plantations followed by best forestry practices resulting in more than 30% productivity jump over the average of 15 m^3/ha/year of the main commercial non-clonal teak plantations. Technologies and forestry practices adopted range from the clonal technology adoption, appropriate selection for planting teak location, soil preparation, nutrition, weed control, pruning, thinning, forest protection and other forestry aspects. This article describes a case study of a large-scale teak plantation company in Brazil that seeks to follow the similar pattern of forest management adopted by eucalyptus and pine. Forest practices, technologies adopted and the main factors to produce teak wood in a large-scale plantation are described.

Teak in Brazil

Until the end of the 20th century, Brazil had been using native forest resources as if they were inexhaustible. Rapidly growing demand for wood for industrial purposes and the increased risk of destruction of native forests led to the enactment of Law No. 5106 of September 2, 1966, enabling growing investments in forest plantations by Brazilian forest-based industries. This policy, in force between 1966 and 1987, was responsible for triggering an intense virtuous cycle of planting at mass scale, expansion, development and forestry research in the South and Southeast regions of Brazil, mainly of the exotic species of *eucalyptus* and *pines* for meeting the wood demand focused on energy and cellulose.

Meanwhile, high quality tropical timber supply and market, such as mahogany, *Swietenia macrophylla*, was sourced from native forest species, largely from the Amazon and was relatively abundant. This may explain, in part, the little interest in teak in Brazil at that time, even after it was introduced in the early 20th century. Experimental teak planting results carried out at the "Escola Superior de Agricultura Luiz de Queiroz" (ESALQ) in Piracicaba, São Paulo state, showed that *Tectona grandis* development was superior to that some native species that produce wood of high commercial value (Sampaio, 1930; Mello, 1963). Since then several other experimental teak plantations were raised across Brazil prominent among which are the teak plantation at Usina Tamoio, Araraquara, in São Paulo state; at Aracruz Florestal S/A, in Aracruz, Espírito Santo; at Jarí Florestal, in Monte Dourado, Pará; and in "Comissão Executiva do Plano de Recuperação Econômico-Rural da Lavoura Cacaueira (CEPLAC)", Porto Seguro, Bahia (Matricardi, 1989).

The first initiative to establish teak stands for commercial purposes took place in Cáceres, Mato Grosso, in 1968, after tests with teak, mahogany and several other high-value native species were carried out by Cáceres Florestal S/A. This teak plantation soon became known for the high price of its wood in the international market (Florestal, 2006). Its success led to the establishment of several large commercial teak plantations in the North and Center West regions of Brazil, namely, small teak stands intercropped with black pepper in Tomé-Açu, Pará state; teak plantation in

Brasnorte, Mato Grosso state, by the Berneck company, a traditional leader in pine cultivation in the south of Brazil; teak planting in Pimenta Bueno, Rondônia state, by the Sulmap company; teak planting in Jangada and Rosário Oeste, Mato Grosso state, by Floresteca.

Teak area expansion in Brazil took place predominantly in Mato Grosso state where it increased from just about 1,480 ha in 1992 to 7,560 ha in 1998 (Caldeira, 1999), to 14,000 ha in 2001 (FAO, 2001). Then it rose sharply to 45,000 ha by 2007 and 65,240 ha in 2009 as registered and updated by the "Associação Brasileira de Produtores de Florestas Plantadas- ABRAF" (Brazilian Association of Planted Forest Producers) (ABRAF, 2007, 2009, 2011; Shimizu et al., 2007). Most recent records place the extent of teak plantations in Brazil at 93,957 ha in 2018 (IBÁ, 2019).

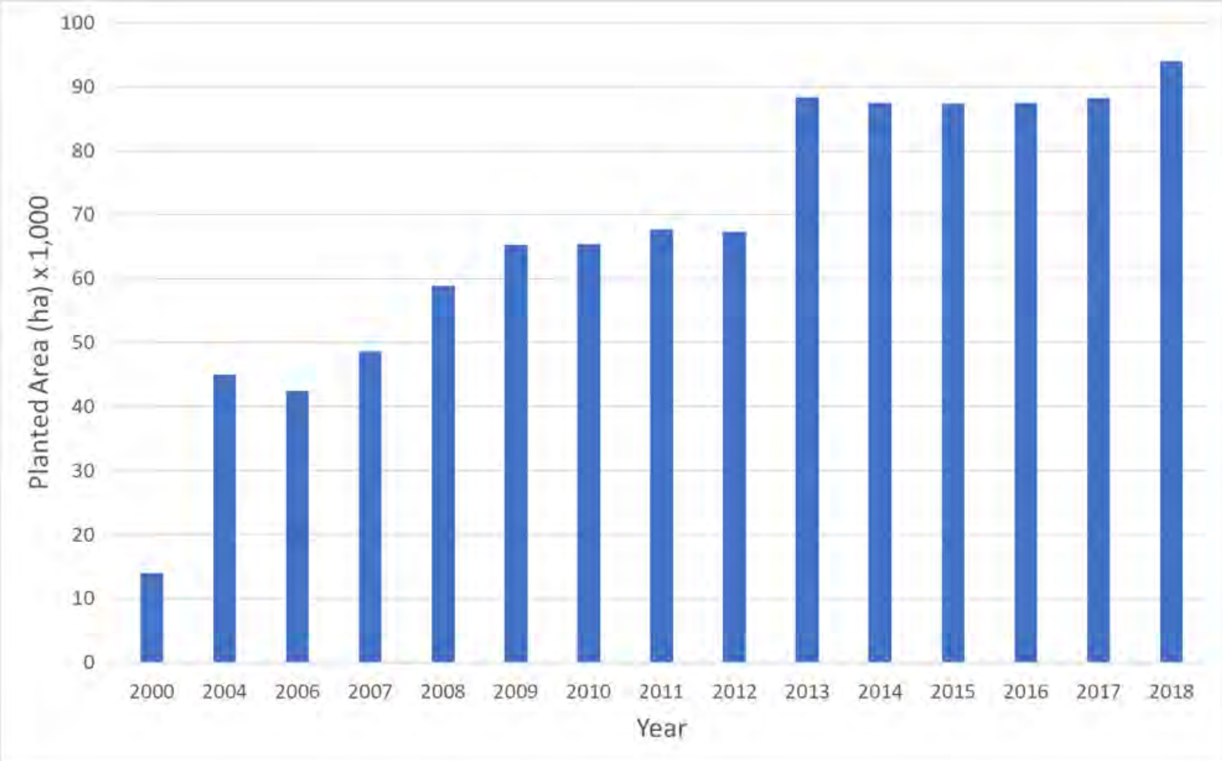


Figure 15-1 Teak planted area evolution in Brazil.

Based on the numbers of Midgley et al. (2015), in which South America has 278,000 ha of teak plantations, Brazil, therefore, represents around 34% of the planted area in this continent. Mato Grosso and Pará are the two states with the largest teak planted area and production of teak wood in Brazil, representing more than 90% of teak in Brazil. The remaining teak plantations are located in Rondônia, Acre, Tocantins, Amazonas, Goiás, São Paulo, Minas Gerais, Bahia, and Pernambuco states.

Since 2013, however, there has been some slowdown in expansion, even reversal in some situations, with several areas being converted to farming after the rotational harvest due to favourable situation for agricultural commodities in the international markets. On a smaller scale, there has also been a replanting of teak plantations after first rotation using clonal technology. The future trend of teak plantations in Brazil is towards stability with a slight decrease in planted area, predominance of clonal plantations, and search for new areas where there is no competition with agricultural commodities.

Characterization and Overview of the Teak Resources Company (TRC) of the Case Study

The following case study was carried out in a company that has just over 40,000 ha of teak plantations established from 1994 onwards that are spread over 100,000 ha of land including more than 29,000 hectares of conservation areas, with forests certified by the FSC® (Forest Stewardship Council®). Their operations comprise a complete cycle in the teak production enterprise: genetic development and production of clonal seedlings; acquisition and selection of areas for planting; soil preparation and planting; forest maintenance and management; harvesting, transport and logistics; processing and marketing (Figure 15-2).

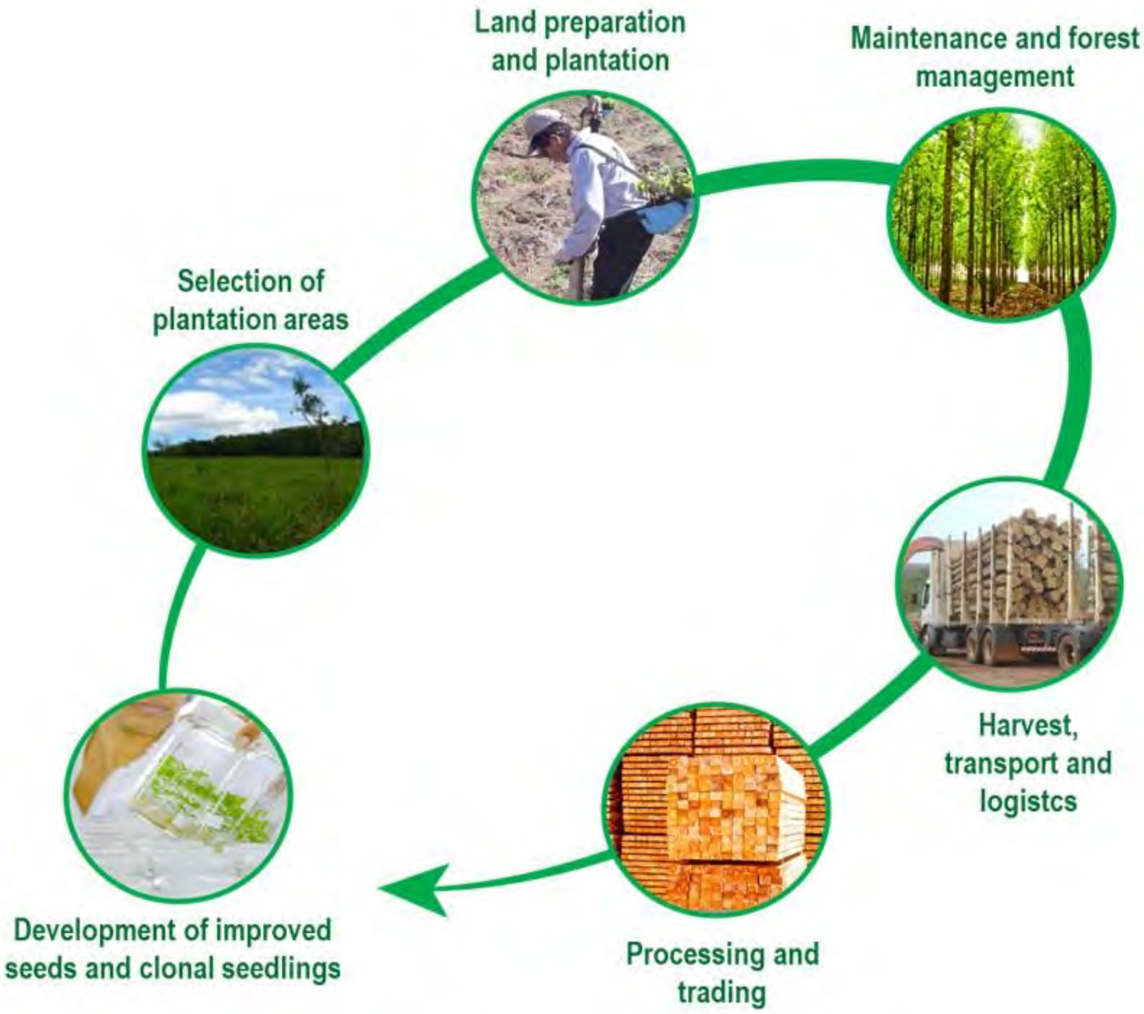


Figure 15-2 Operations of the company of the case studied.

In 2020, 150,000 m^3 of logs were produced, with a projection to produce 250,000 m^3 in 2022. Its forestry operations cover 36 farms between the Pará and Mato Grosso states, 1 industrial unit for the sawn teak wood production in Mato Grosso, with an administrative office in São Paulo state, and sales offices in Singapore and Taiwan (Figure 15-3), more than 800 direct jobs, indirectly impacting more than 3,000 people.

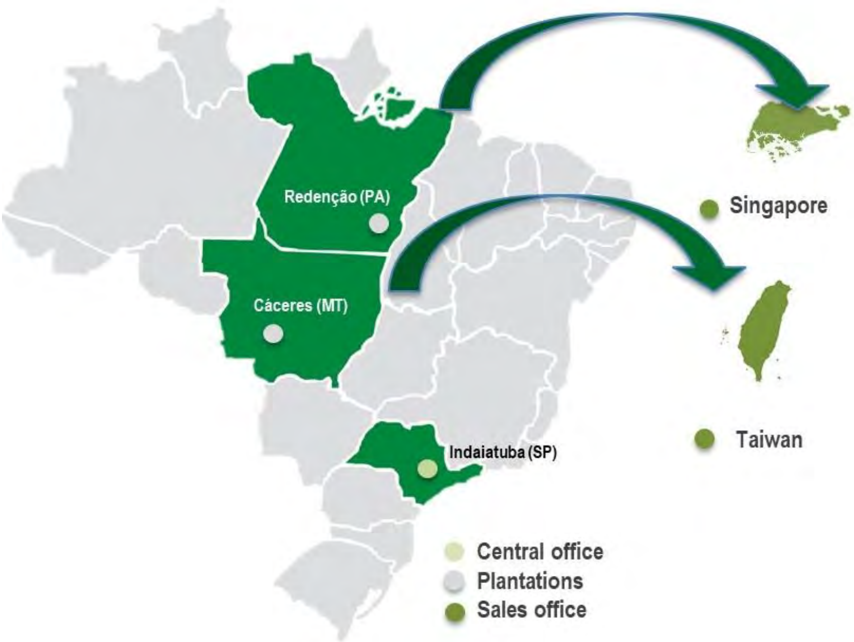


Figure 15-3 Forests and office location of the company of the case studied.

Managed plantations of the company began in 1994, in Mato Grosso. Forest certification management, according to the principles and criteria of the FSC®, was introduced in 1998 and clonal technology has been in use since 2001. Sawmill was established in 2003 and the company began exporting its product at scale in 2005. By 2006 the company was able to sell its CO_2 credits generated.

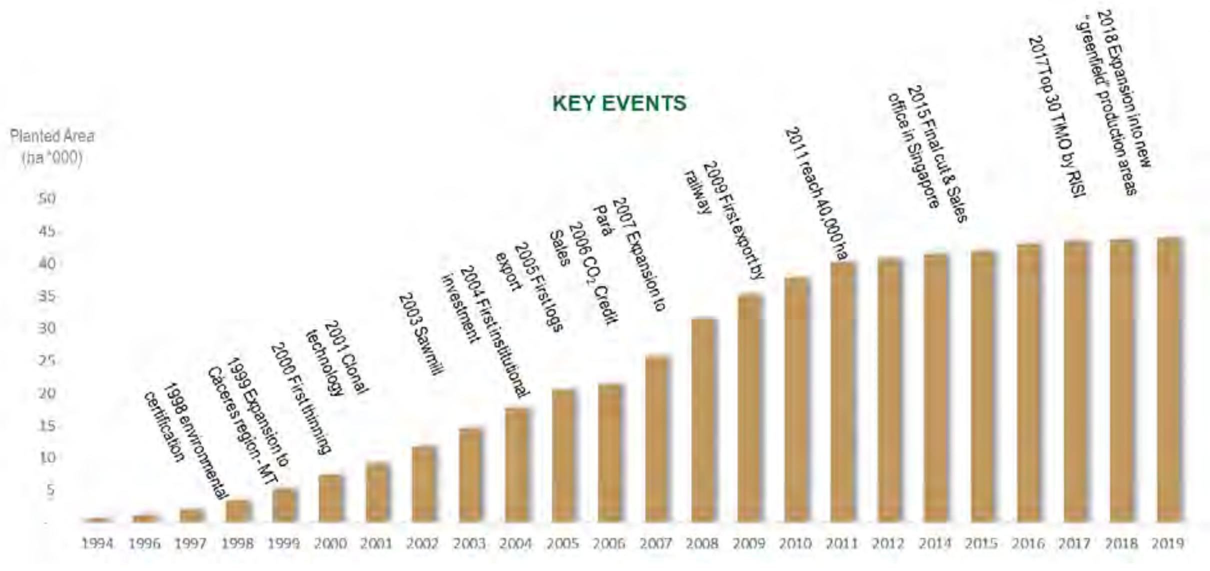


Figure 15-4 Planted area evolution and history.

Silviculture and Forest Management

Genetic improvement

A teak genetic improvement program seeks to ensure supply of high-performance genetic materials, higher productivity, good stem quality, wood and heartwood proportion, resistance to diseases and adapted to the site and climate conditions (Bhat & Ma, 2004). Genetic improvement is the primary strategy applied by this company to increase and maintain the productivity and quality of teak wood, as well as to mitigate phytosanitary and climatic risks.

In 2001 the company introduced superior teak clones using genetic materials originating from a laboratory in Malaysia. Since then, it has intensified the actions of its teak genetic improvement program in Brazil that include:

- ✓ Enlargement of its genetic base from the mass selection of superior trees in its commercial plantations of seminal origin (Photos 15-1 and 15-2) and introduction of teak genetic material (genotypes) from different families and geographical origins. There are currently more than 200 genotypes in its genetic improvement program;
- ✓ Establishment and conduct of provenance, progeny and clonal tests;
- ✓ Application of techniques to achieve controlled cross pollination (Photo 15-3) and early flowering;
- ✓ Development of the genomic analysis technology that can be applied to teak genetic improvement including complete genome sequencing to obtain the punctual variations along the DNA.

Photo 15-1 Superior tree selected for 72 cm dbh at 20 years rotation

Photo 15-2 Micro cuttings from genetically superior trees rejuvenated and multiplied

Photo 15-3 Pollen collection and controlled pollination in teak

Photo 15-4 Mini clonal garden to produce mini cuttings of superior genotypes

Photo 15-5 Mini cuttings into tube for rooting

Seedling production

Its nursery is located on the side of a little river and supplied by an artesian well, obtaining quality water for all its irrigation, with an installed capacity to produce 600,000 clonal seedlings per year. Clonal seedlings production process begins with the collection of mini-cuttings from mother plants from mini-clonal garden (Photo 15-4). A mother plant can produce a huge number of cuttings throughout the year and at each collection event between 2 to 4 mini cuttings are collected. Generally, each cutting will give rise to a new plant or seedling.

The mother plants originate from proven superior genetic materials and properly rejuvenated. Mini cuttings are placed into tubes (Photo 15-5) with a capacity of 55 cm^3 containing a commercial substrate of turf, vermiculite, organic residue (carbonized rice straw), to which a slow-release fertilizer is added. The substrate must be well aerated, free of pathogens and contaminants to ensure healthy and quality seedlings production.

Mini cuttings root easily under specific greenhouse conditions, then transferred to a shady place (Photo 15-6), and finally put under direct sunlight. Clonal seedlings become ready (Photo 15-7) for definitive planting after about 90 days in the nursery.

Photo 15-6 Greenhouse for rooting mini cuttings

Photo 15-7 Seedlings ready for planting in the field

Planting site selection

Planting site selection suitable for teak follows criteria based on soil characteristics, climatic conditions, topography, transport and logistics infrastructure, energy, and human resources availability. The selection areas procedure to plant teak involves an analysis of the geological origin of the soils (Granodiorite, Basalt, Tonalite and others), prior analysis of the soil, physical, and chemical characteristics, a field survey and elaboration of thematic maps, indicating the soil characteristics and its main limitations (Figures 15-5, 15-6 and 15-7), being key information for recommending the best use of available soils, preparation, and correction of chemical and physical soil conditions.

Figure 15-5 Soil water influence depth thematic map

Figure 15-6 Soil texture thematic map

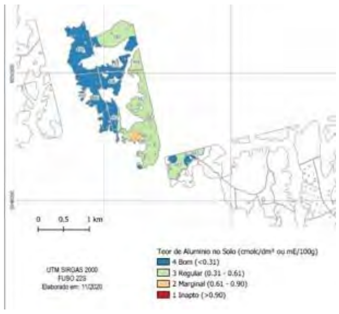


Figure 15-7 Soil aluminium thematic map

Maps are also generated to plan implementation and planting operations, including teak stands design, roads, firebreaks, facilities, and infrastructure for supporting, as well as the delimitation and respect for conservation and environmental protection areas. Special attention is given to the maintenance and protection of the remaining forests within the property and conservation of representative samples of the ecosystem and areas that must be protected by law. Sites choice and recommendation of the improvements in the physical and chemical conditions of the soil are relevant and decisive for the success of establishment and development of a high yield and quality teak stand.

Soil improvement and planting

Soil improvement activities make physical and chemical soil conditions suitable for planting, establishment of teak seedlings and the people and machines transit in future management activities into the stand. It is carried out using the minimal tillage technique, in which the soil is only rolled along planting line, keeping old pasture residues between planting lines to protect the soil. It consists of an herbicide application based on glyphosate for desiccation of the grasses and herbaceous vegetation of the old pasture (Photo 15-8); in some situations a pre-emergence herbicide based on oxyfluorfen is also applied to control emergence of weeds in future. After those planting lines are demarcated and a subsoiler implement is used to break top layer of soil compaction. There are cases of soils with greater physical restrictions in which an implement with both subsoiler and plough disks is used (Photo 15-9) building a soil bedding on the planting line further increasing the volume of soil exploited by teak roots.

Photo 15-8 Old degraded pasture being prepared for teak planting

Photo 15-9 Bedding plough with subsoiler

At this stage maintenance of existing roads and new roads constructions are carried out for easy access to different stands compartments for future management, harvesting and wood transport. Based on the soil chemical analysis sources of Calcium and Magnesium are added for correction and maintenance of soil fertility purpose at least 2 months before planting. These sources could be dolomitic limestone or/and plaster, to correct soil acidity and neutralize Al (Aluminium), in addition to providing Ca (Calcium) and Mg (Magnesium). The planting operation takes place at the beginning of the rainy season in order to maximize rainy season window for a good start of initial growth.

Planting is carried out manually, with the support of an equipment called “matraca”, using selected high quality, healthy and superior genetic seedlings (Photo 15-10). Workers are trained so that there is no excessive covering of the seedlings stem by soil, a failure that can drown the collar and delay the growth of seedlings besides possibly causing phytosanitary problems in future. The spacing varies between 5x5 meters, 6x4 meters and 7x4 meters, according to the region and soil and slope conditions. During planting it may be necessary to apply fertilizers with adequate sources of P hosphorus to keep planting mortality very low, usually below 5%. The practices adopted have allowed for a good initial start and uniform seedlings growth (Photo 15-11).

Photo 15-10 Teak manual planting with "matraca"

Photo 15-11 Teak clonal stand, good and uniform initial growth start

Time between seedlings shipment from the nursery until effective planting does not exceed 15 days during which period the seedlings are kept in a shaded place and receive constant irrigation.

Currently, the company plants only seedlings originated from clonal material with proven superior genetics. Compared to seed origin material of the first stands, the oldest clonal material, at 17.5 years old, presents 60% higher individual volume (Figure 15-8) and 20% increase in dbh (Figure 15-9).

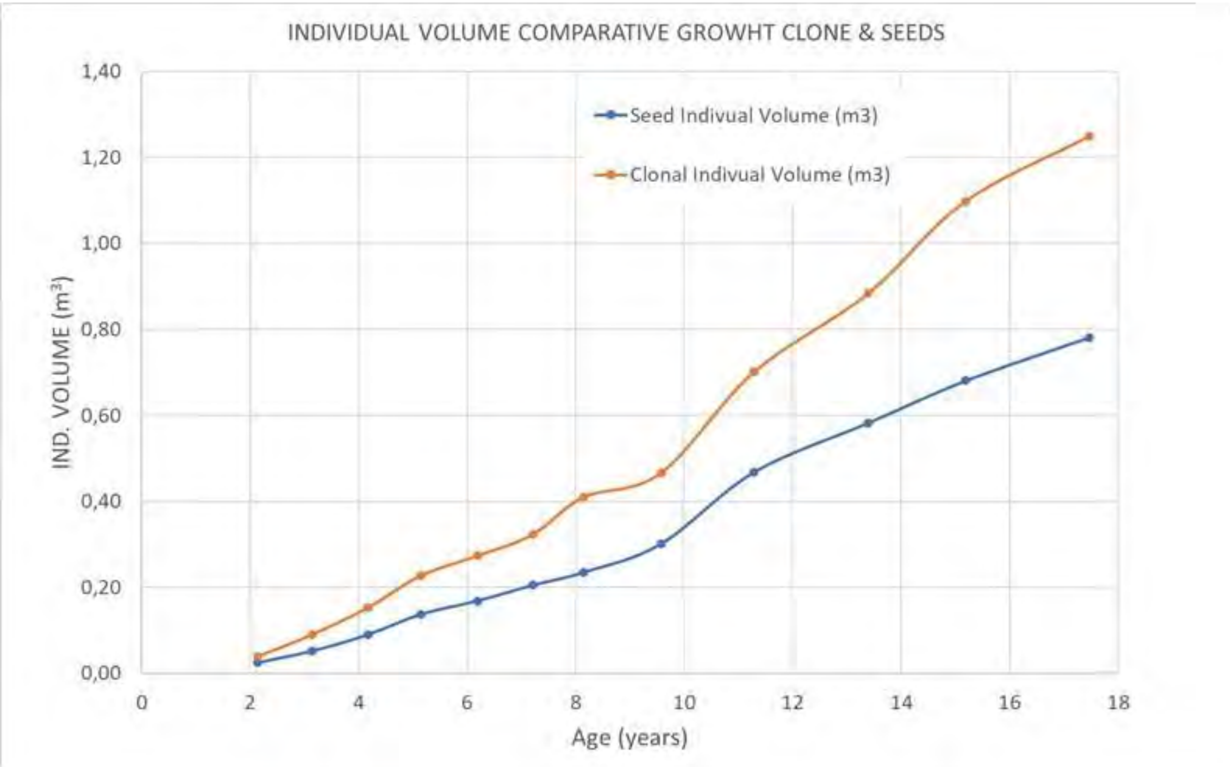


Figure 15-8 Growth in individual volume, comparing clone and seed, 17.5 years

Figure 15-9 Growth in dbh, comparing clone and seed, 17.5 years

The company prioritizes productive use and has expanded into old pastures areas, generally degraded, improving and optimizing land use, with no conversion of forests and native vegetation to teak plantations, even if permitted by law.

Forest Maintenance/Management

The first years of teak stand demand greater attention, with greater intensity, frequency and need for manpower. Weed control, fertilization and pruning are the main activities in the early years. In the first 3 years, weed control is essential to ensure good initial development and growth, because a failure in this activity causes growth loss due to weed competition for water, nutrients, and light; it can be performed manually, mechanically, or chemically. Manual weeding is carried out in the planting row, weeks after planting, when seedlings are still small and young. Mechanized weeding is carried out between the rows, usually with mechanized brush cutters. Chemical weeding with glyphosate application is preferred. However, when the seedlings are still small, below 1.5 meters in height, proper protection is necessary, so that herbicide does not reach teak leaves (Figure 15-5). When the teak plants reach a height above 1.5 m it is possible to apply herbicide without protection, as the risk of the herbicide reaching the teak leaves is low.

Figure 15-12 Chemical weeding in the planting line

Fertilization (Figure 15-13) assumes that chemical and physical soil analysis results indicate the need for it. The supply and balance of the main essential nutrients (N, P, K, Ca, Mg, B, Zn etc.) guarantee the proper start and maintenance of teak growth throughout its rotation. The decision on sources, dosages and timing of fertilizer application is based on soil analyses, stand growth results and visual foliar diagnosis of symptoms associated with nutrition.

Figure 15-13 Application of fertilizer in the teak stand

Pruning ensures a good quality stem conduction, minimizing defects caused by dead knots in the wood, a necessary activity throughout the rotation, but drastically reducing its intensity and frequency from the tenth year onwards. It is performed manually with a pruning saw and in a semi-mechanized way with a combustion equipment called pole prune saw (Figure 15-14). For heights above 2 meters, such tools and equipment are coupled to a pole allowing reach up to 5 meters. The height of the pruning is limited to half of the total height of the trees and seeks to concentrate the pruning during the dry period of the year, mitigating the potential diseases risks that affect teak trunk.

Figure 15-14 Pruning with a pole prune saw

Other activities are also carried out during forest maintenance, such as controlling leafcutter insects, and roads and firebreaks maintenance. It is important to emphasize that chemical products use, such as herbicides and insecticides, is always in strict compliance of the FSC® pesticide policy.

Forest harvesting

Forestry planning offers necessary support for decision making in order to optimize financial returns and ensure the sustainability of quality teak wood supply to the market. Currently, the final harvest adopted by the company is carried out between 18 and 20 years, with 3 or more thinnings throughout the rotation, according to the stand growth monitoring results.

Continuous forest inventory system and decision support tools provide important indicators for understanding teak stand growth dynamics, wood stock evolution, different scenarios simulation, etc. These form the basis for guiding decisions such as the appropriate age and intensities of thinning and final cutting to achieve optimal forest management.

For thinnings, trees selection and marking are carried out following preset guidelines that ensure removal of diseased, crooked, and bifurcated trees as well as smaller diameters allowing uniform spatial distribution among the remaining trees. It is through selection and marking activity that the future trees of the final harvest are chosen that will bring better wood quality and greater economic returns.

Harvest (Figure 15-10) starts from a detailed operational planning using drone images using geographic information system, pre-determining machines route and points to locate wood piles, helping to do harvest operation more efficient and lower cost. Performed primarily in a mechanized way, minimizing accidents risk, preserving the workers health and safety, it consists of harvesters and feller bunchers to felling trees, logs forwarding and loading which are mechanized with self-loading tractors and forest loaders, and wood transport is carried out in trucks adapted for the transport of logs.

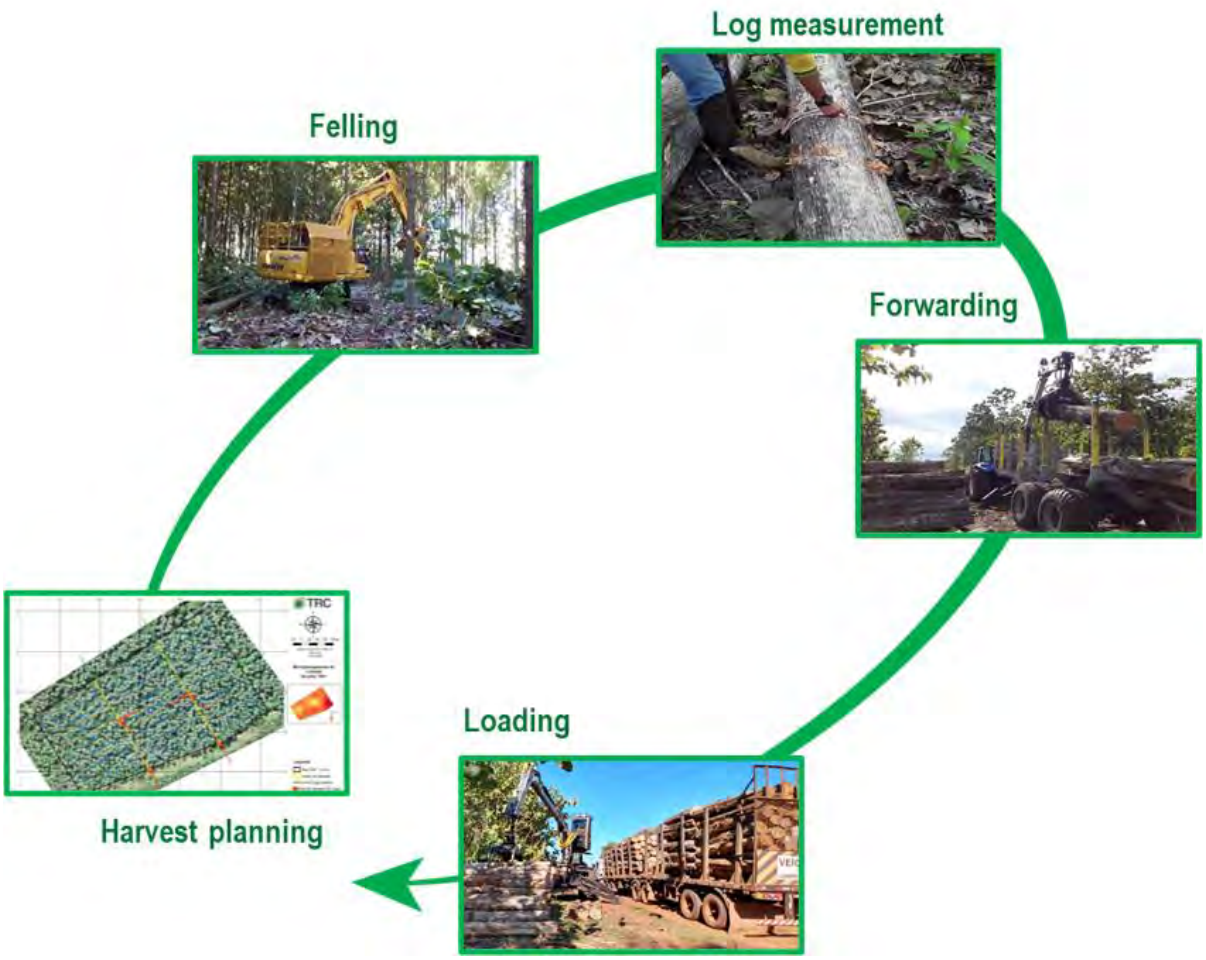


Figure 15-10 Activities carried out in the harvest

Logs measurement and labelling are performed manually ensuring the accuracy of length and circumference for more than 50 different measurements and types of logs.

Production and log market

Procedures adopted in the teak wood harvesting and transport guarantee the integrity, stability, efficiency, and traceability throughout the supply chain, delivering products at the destination.

All transport track, from road (Photo 15-15), rail (Photo 15-16) and sea, as well as some services along the logistics chain is outsourced (Photo 15-17).

Photo 15-15 Logs being transported by truck

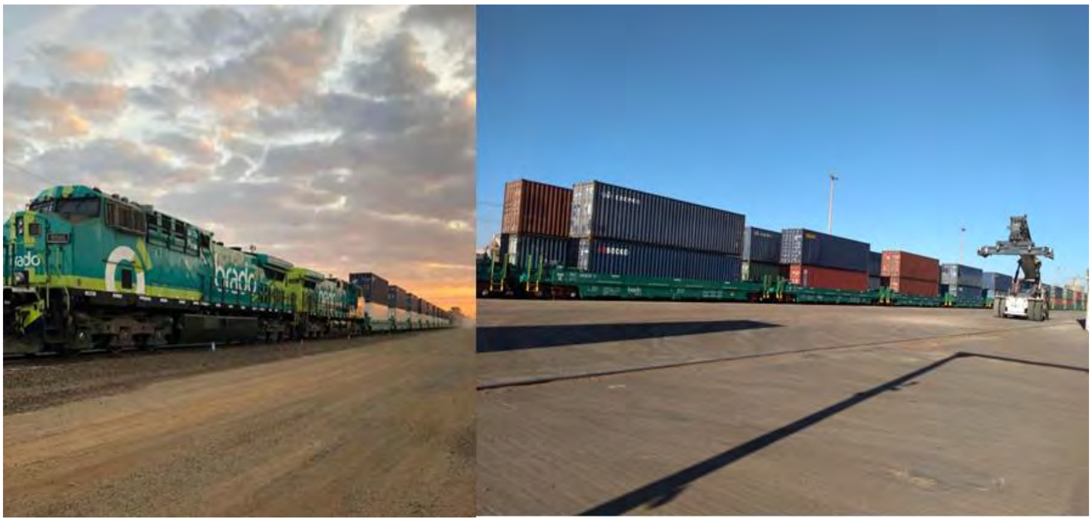


Photo 15-16 Train and wagons transporting teak wood

Photo 15-17 Logs being placed inside containers

More than 100,000 m^3 of teak wood (Photo 15-18) was sold by the company in 2019 and 150,000 m^3 in 2020. It has more than 140 customers from 13 different countries in the last 12 months. The main markets served are sawmillers that process wood for the construction, furniture, flooring, deck and veneer sectors (Photo 15-19).

Photo 15-18 A pile of teak logs for export

Photo 15-19 Teak wood products

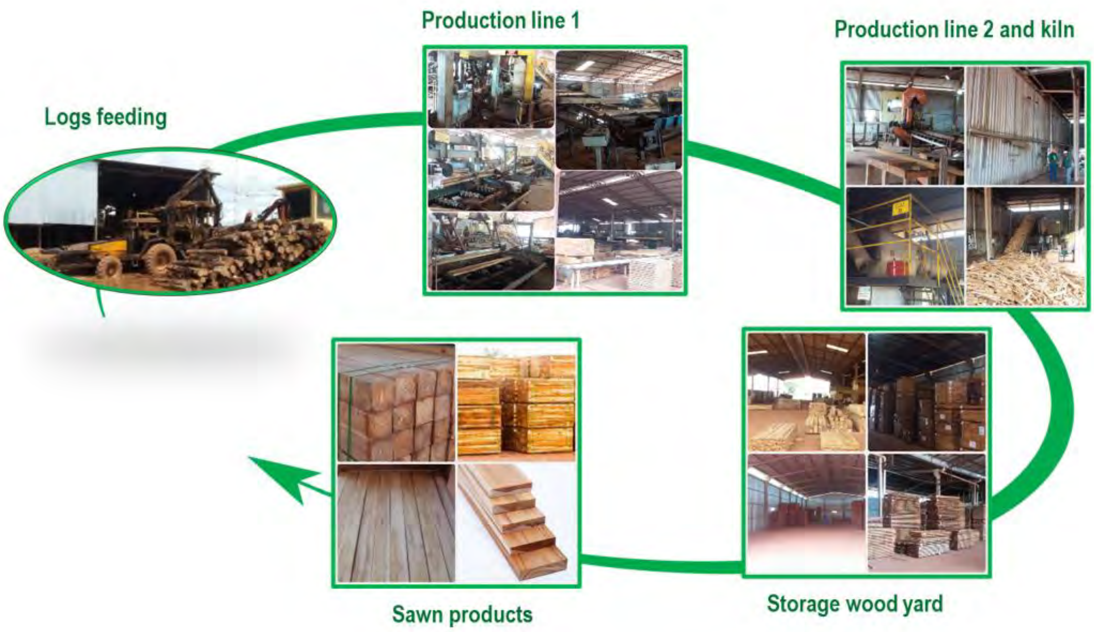


Figure 15-11 Composition of the sawmill

Sawmill

The sawmill (Figure 15-30) comprises production line 1, with a band saw, dedicated to smaller logs and larger-scale production; production line 2, with a car saw, dedicated to larger logs and a kiln for drying boards.

Located at the Industrial District of Cáceres, Mato Grosso, with an installed production capacity over 50,000 m^3 a year of sawn products between blocks and boards, employs around 80 local workers. Sawn products make it possible to improve the economic efficiency of logs with restrictions due to their size in the export log market and allow diversification of products offered to the market. The sawmill has FSC® chain of custody certification, guaranteeing that its certified sawn products originate from its forests, whose management is also certified by the FSC®. It should be noted that the sawmill's management follows not only all the environmental legislation required for such industrial activity with the appropriate environmental licenses as well as strict safety and health procedures for its worker, required by Brazilian legislation.

Environmental, Social, and Corporate Governance Principles

The company of this case study, since the beginning of its activities, has already adopted responsible practices and this fact was validated by the FSC® environmental certification received in 1998 followed by the chain of custody certification.

This teak plantation enterprise model can help to alleviate the pressure on native forests by offering sustainable supply of teak timber and mitigate climate change effects by converting land use from old and degraded pastures to teak stands thereby ensuring restoration, protection and conservation of environmental reserves under its management. Also teak plantations, by the nature of their long cycle when compared to other species and the use of teak wood to manufacture durable goods, make the carbon balance positive with a high rate of environmental and social benefits that will continue to be stored for a long period.

The environmental conservation areas supports more than 166 species of birds (Photo 15-20), 30 mammals species (Photos 15-21 and 15-22) and 120 of native flora species, many of them, endangered species.

The company has initiated a project titled Sunrise Project (Photo 15-23) for research on transition from combustion pruners to electric pruners using solar energy.

Photo 15-20 Macaws in the conservation areas

Photo 15-21 Tapirs inside teak stand

Photo 15-22 Jaguar family on the side of the road at the teak plantation farm

The company employs more than 800 workers directly and indirectly impacts the livelihood of more than 3,000 people positively. In 2020 the company invested a hundred thousand dollars in social actions benefiting more than 250 people distributed in 4 different municipalities. Among the social projects, Toque de Letra Project (Photo 15-24) bring consciousness to citizens from needy communities towards their civil rights and duties through promoting sport activities as socialization tool.

Photo 15-23 Electric pruners of Sunrise Project

Photo 15-24 Toque de Letra Project

Recommendations

Based on the reported case study (Photos 15-25, 15-26 and 15-27) the recommendation for a large-scale teak plantation in Brazil and South America are as follows:

- ✓ Choosing suitable sites and improving the chemical and physical soil conditions of the soil, when necessary. Deep, well-drained, aluminium-free soils, good fertility with adequate levels of NPK, Ca, Mg and micronutrients;
- ✓ The use of superior genetic material, healthy and quality seedlings;
- ✓ Weed control, especially in the first 3 years, more intensive pruning until the tenth year and thinning throughout the entire rotation should not be neglected.
- ✓ Workers and partners engaged and aligned with the enterprise's strategy, objective and culture;
- ✓ Long-term cycle, high value of wood and increasing market demand, make it essential to have an adequate financial source, greater relevance of the financial aspects of management, good corporate governance and good management practices of socio-environmental responsibility.

Photo 15-25 Part of the company team during the Internal Work Accident Prevention Week

Photo 15-26 Mosaic aerial view of the teak plantation respecting conservation areas

Photo 15-27 Teak trees into stand

References

ABRAF (Associação Brasileira de Produtores de Florestas Plantadas) (2007) *Anuário Estatístico Da ABRAF 2008: Ano base 2007*, Brasília, Brazil.

ABRAF (Associação Brasileira de Produtores de Florestas Plantadas) (2009) *Anuário Estatístico Da ABRAF 2009: Ano base 2008*, Brasília, Brazil.

ABRAF (Associação Brasileira de Produtores de Florestas Plantadas) (2011) *Anuário Estatístico Da ABRAF 2011: Ano base 2010*, Brasília, Brazil.

Bhat, K. M. & Ma, H. O. (2004). Teak growers unite! *Tropical Forest Update,* 14(1), 3-5.

Florestal, C. (2006). *Manual do reflorestamento da teca. Cáceres, Mato Grosso*. 30 p. Available in: http://www.caceresflorestal.com.br/Plano_de_Manejo_Florestal_da_Caceres_FlorestalResumo.pdf.

Caldeira, S. F. (1999). *Práticas silviculturais. Notas de aulas teóricas*. Introdução às práticas silviculturais. Universidade Federal de Mato Grosso. Faculdade de Engenharia Florestal. Departamento de Engenharia Florestal, Cuiabá, Brazil.

FAO (Food and Agriculture Organization) (2001). *Global Forest Resources Assessment 2000*. Main Report FAO Forestry Paper 140, Rome, Italy.

IBÁ (Indústria Brasileira de Árvores) (2019). *Relatório 2019*, São Paulo, Brazil.

Matricardi, W. A. T. (1989). *Effect of soil factors on the development of teak (Tectona grandis L.f.) cultivated in greater*

Cáceres – Mato Grosso. MSc thesis, Forest Sciences. Higher School of Agriculture "Luiz de Queiroz" University of São Paulo, Piracicaba, Brazil.

Mello, H. A. (1963). Alguns aspectos da introdução da Teca (*Tectona grandis* L.) no Brasil. *Anuário Brasileiro de Economia Florestal,* 15(15), 113-119.

Midgley, S., Somaiya, R. T., Stevens, P. R., Brown, A., Nguyen, D. K. & Laity, R. (2015). *Planted teak: global production and markets, with reference to Solomon Islands*. ACIAR Technical Reports No 85. Australian Centre for International Agricultural Research, Canberra, Australia.

Sampaio, A. J. (1930). A teca da Índia e a do Brasil. *Revista Florestal,* 1(9), 7-10.

Shimizu, J. Y., Klein, H. & Oliveira, J. R. V. (2007). *Diagnóstico das plantações florestais em Mato Grosso*, Cuiabá, Brazil.

SECTION IV:

SUSTAINABLE TEAK FOREST MANAGEMENT AND CERTIFICATION

Chapter 16: Teak Timber Harvesting

Nopparat Kaakkurivaara

Abstract

Timber harvesting is an essential and cost-intensive activity in forest management. It involves cutting trees and moving them to a landing, processing, sorting and loading, and transporting materials. The felling and extraction of timber is potentially a very dangerous operation and harvesting crews are required to be highly skilled and well trained. Poor planning and/or poor implementation can be costly, result in environmental degradation as well as excessive harvesting waste, ineffective utilization of wood, and injury to personnel. A carefully managed, sustainable timber harvest is not just about cutting down trees and earning their commercial value. It is about implementing a plan that encourages regeneration and the long-term well-being of the woods.

The resources, equipment, and machines that can be used in timber harvesting are diverse and can be composed in complex systems. Many countries are facing a lack of financial resources for using their forests in a competitive and sustainable way. Logging companies with better financial background are able to mechanize harvesting processes and increase productivity and working safety. While, smallholders are still relying on simple tools and equipment, animal skidding, and manual or motor-manual work in harvesting operations. The present chapter gives an overview on the existing methods, equipment, and machines that are available for Teak harvesting operations in Makong region.

Introduction

Sustainable Forest Management (SFM) is the process of managing forest to achieve clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction in the forest's inherent values and future productivity and without undue undesirable effects on the physical and social environment (ITTO, n.d.). This definition implies the critical importance of safeguarding the environment and the livelihood needs of forest-dependent communities. One of the reasons for the slow implementation of SFM is related to how to effectively protect the environment and the people who depend on forests. Timber harvesting, when not carried out properly, can lead to serious environmental degradation and negative impacts on local communities. But if timber harvesting is well planned and implemented, it can generate many economic and social benefits with only marginal impacts on the environment. In tropical forests designed for timber production, selective logging can be considered as a silviculture technique to ensure minimum impacts on the environment.

Forest harvesting can be defined as *"The aggregation of all operations, including pre-harvest planning and post-harvest assessment, related to the felling of trees and the extraction of their stems or other usable parts from the forest for subsequent processing into industrial products"* (Dyksta & Heinrich, 1992, 1996). Thus, harvesting is not only felling and extraction of the trees but also includes the planning beforehand and impact assessment after the operations in order to take all concerns into considerations for the next harvesting.

Harvest Planning

Harvest planning provides a balanced and comprehensive foundation for sustainable harvesting practices to enable good technical control during harvesting reconciled with the need for reducing harvesting costs. Harvest plans are of two types, strategic and tactical (Klassen, 2011)

A strategic harvest plan explains why, where, when and what type of harvesting is proposed. Strategic harvest planning cannot be undertaken without considering the issues which affect the management of the forests more widely. It is a basic part of forest management plan, prepared by the planning team, and should never be a separate planning statement.

A tactical harvest plan is a short-term plan, prepared by a team directly responsible for supervision of harvesting operations, that explains how and who will carry out the operations and when cutting will be undertaken in each cutting area. A Tactical Harvest Plan can apply to a single felling area or to a group of separate felling areas and is linked to the approved forest management plan through the Annual Plan of Operations.

The following basic steps are involved in tactical harvest planning (Applegate *et al*., 2004):

- A pre-harvest inventory should be conducted to identify tree species, to estimate the size and volume of trees present and their position throughout a felling area. The inventory should extend over the whole area where harvesting is proposed. In the case of selection harvesting, trees to be cut should be identified, marked, and numbered.
- A topographic survey, either on the ground or using remote sensing imagery, should be conducted during a pre-harvest forest inventory to provide information for mapping.
- A detailed topographic map should be drawn, showing all topographic features that will influence logging, and the boundaries of the harvest area. Set aside area, buffer zone, conservation areas, watercourses, wildlife habitat, and any other special reservations specified in a management plan should be mapped. Contour mapping can be prepared either by manual drafting methods or using GIS technology. It is the experience of many companies who are managing tropical forests that an investment in good quality mapping can lead to reduced impacts and lowered infrastructure costs.
- A skid trail network from the chosen landing needs to be laid out and mapped taking into account all concerns regarding environmental impact, economic viability, skidding distance, and terrain features. This map is used to guide field reconnaissance and actual skid trail places.

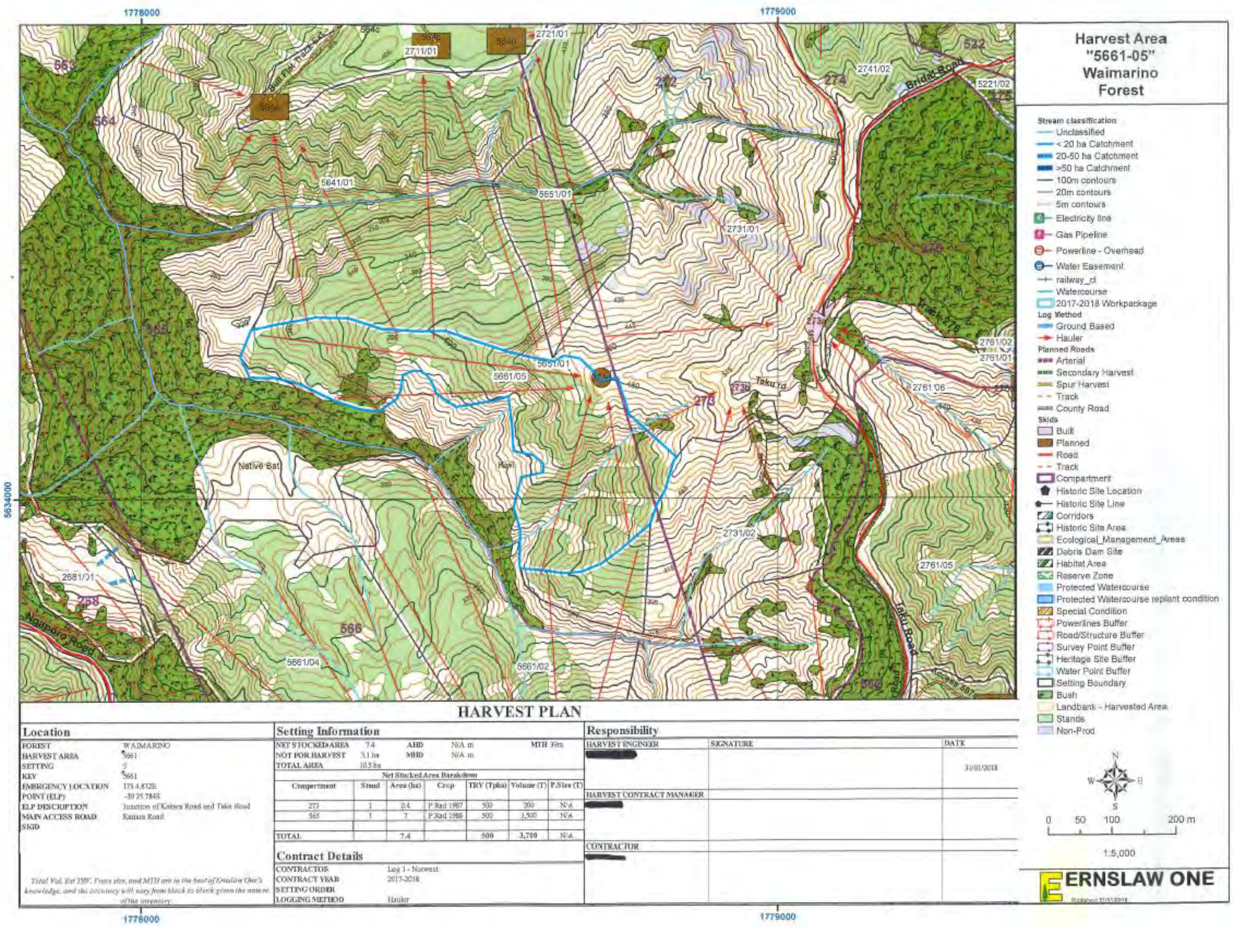


Figure 16-1 Example of harvesting plan

Specific planning requirements are:

- Tactical harvest planning should be based on harvesting prescriptions set out in a forest management plan. The volume and/or number of trees per hectare to be extracted and the number of seed trees per hectare that are to be retained should be specified.

- A cutting and log extraction plan should comprise a part of the harvest plan and should be undertaken using the topographical and tree position map. It can also be generated using vertical and oblique GIS imagery. The plan should be prepared jointly by forest planners and loggers and must be practical and realistic. The location of landings, skid trails (if ground skidding is to be used), cableways (if cable extraction systems are to be used), and haul roads should be shown. Where possible, directional felling should be indicated.

o Harvesting equipment should be specified and a general operations schedule formulated, using actual or estimated production rates. Work studies may be necessary to determine appropriate production rates.

o A harvesting schedule should be prepared setting out the estimated timing of harvesting in different felling areas. It should be flexible and able to be quickly modified, when necessary.

o Preparation of a harvesting schedule should, where applicable, be prepared in consultation with local communities who might be affected by harvesting. The harvest of NTFPs and the dependency of local communities upon these for subsistence, employment and income generation should be considered. Examples are collection of rattan, mushrooms, bamboo shoots, and medicinal plants.

o Any legal requirements, should be listed, for example, harvesting and transport permissions, chainsaw use permission, and obtained.

Teak Timber Harvesting

Since logging in natural forests is banned, timber production in Thailand has shifted from natural forests to planted forests, particularly in the case of Teak. The Tree Length (TL) method is mostly used for Teak harvesting in which trees are felled, delimbed and topped using chainsaws within the compartment itself and only the bole is extracted to roadside by animal power (elephant), tractor, or skidders. Theis is then followed by short distance transportation between roadside landing to main log landing for further processes such as log measuring, cross cutting, and stacking (Figure 16-2).

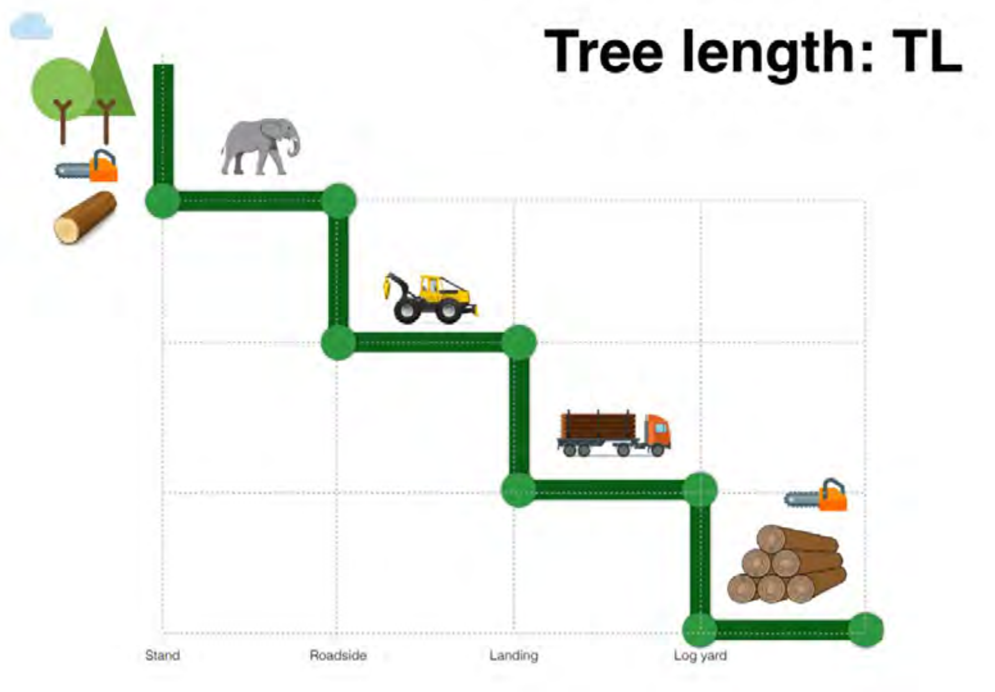


Figure 16-2 Harvesting process of Teak harvesting in Thailand

Felling

The general rotation of Teak from plantation is about 30 years preceded by two thinnings at 15 and 25 years. Trees to be cut are marked with paint beforehand by local forest manager. Felling crew consists of 2-3 men, one chainsaw operator together with two assistants for felling direction control. Crew normally work for about six hours a day. After trees are felled the branches are removed right away. The average effective productivity of felling is 29.81 m^3/h, where average stump diameter, log length, and log volume are 32.39 cm, 13.04 m, and 0.86 m^3, respectively (Rianthakool et al., 2018).

Photo 16-1 Tree felling with chainsaw

Extraction

Timber extraction from stump area to roadside is either by animal power or mechanized method i.e. tractor or skidder (Photo 16-2). The most common animal power is elephant. Elephant logging is common in many parts of Asia like Thailand and Myanmar. The advantages of using elephant lies in their ability to access steep terrains and forests without road network, and no consumption of fossil fuels. However, the limitations of using elephants are low productivity compared to other methods, short skidding distances, working hours limited to mornings, and the time taken for healing if elephant gets sick. The average productivity of extraction by elephant is 11.11 m^3/h for skidding distances shorter than 100 m. with an average of 2.75 logs or 0.68 m^3 per work cycle (Rianthakool et al., 2018). In places, where mechanized skidding is available, mechanized skidding is preferred since it provides higher productivity compared to animal power. The average productivity of mechanized skidding varies between 10-25 m^3/h depending upon the type of machine but impact on soil and water is a big concern if timber extraction is in steep terrain.

Photo 16-2 Timber extraction

Short distance transportation

The short distance transportation between roadside of harvesting site to permanent log landing is sometimes known as primary transportation. It is an internal timber transport inside the plantation itself. There are various types of vehicles for this sort of transportation, for example, crane truck, trailer together with front end grapple loader, or self-loading truck (Photo 16-3). The average productivity of short distance transportation is 9.23 m^3/h, with average 1.77 kilometers of transporting distance (Rianthakool et al., 2018).

Photo 16-4 Examples of short distance transportation vehicles

Processing

Once timbers are transported to log landing the next step is log measuring, cross cutting, log identifying (hammer branding), and finally stacking for sale (Photo 16-4). Log measurement is conducted manually for log length and diameter in order to decide where to cross cut. Average productivity of this process was 330 logs/h (Rianthakool et al., 2018). Afterwards the chainsaw operator team takes over for cross cutting as marked by the log measuring crew. The average productivity of cross cutting by using chainsaw is 170 logs/h with averaging 20.94 cm of log diameter (Rianthakool et al., 2018). After logs are cut the log serial number is stamped on log surface with hammer branding. The serial number represents traceability system to reflect where the logs come from and when it has been harvested. The average productivity of hammer branding for log identity is 207 logs/h (Rianthakool et al., 2018). Eventually, the logs which have similar characteristics (diameter and length) will be stacked together in one pile (approx. 6-7 m^3) for bidding. Forest owner usually set minimum price according to log diameter, log volume, and quality.

Photo 16-4 Log processing

Generally teak logging operation is time-consuming because teak normally grows on mountainous area that are very steep in some places, and the harvesting is more or less labor intensive operation. It is seen that there is high productivity in felling stage but lower productivity in extraction and primary transportation leading to bottleneck problem in work flow. This problem can be tackled by increased resources, i.e. number of workers or machines. There are two methods to increase productivity in the extraction process, namely, the introduction of higher efficiency machines and reorganizing work processes.

Work Safety

Forestry is one of the most dangerous of occupations; it is sometimes called a “3D” job – dirty, difficult and dangerous. Forest harvesting on steep terrain is always a challenge in terms of safety, operating costs, and environmental impact. Kaakkurivaara & Stampfer (2018) have indicated an extremely high fatality rate in Thailand compared to the average in other countries. Possible reasons for this may include ineffective safety regulations, seasonal forestry workers, inadequate worker training programs, and a lack of personal protective equipment. A safe harvesting operation is an efficient harvesting operation, not only because it reduces the potential for loss, but also because it increases production, improves the working environment and overall improvement in attitude and morale of workers. Occupational health and safety in forestry can be greatly improved through adequate worker training and supervision and the use of safety equipment, among other things.

The most common causes of accidents is the workers' lacks of knowledges or skills. Training is one of the most effective tools in controlling risk. Employees should be trained to work along with the systems and work safely. The employer should ensure all employees have been adequately trained and instructed to perform their employment safely before allowing them to work in harvesting operations. Workers should be made aware of relevant dangers involved with their work and of any safety precautions that should be taken to avoid accidents or injury. Additionally, wearing suitable PPE can provide protection for workers when all other control measures cannot adequately eliminate or minimize risks to a worker's health and safety. A wide range of PPE is available to help minimize the risk of injury to forest workers and the employer is expected to evaluate the risks involved in each job and select suitable PPE for specific tasks.

Personal Protective Equipment (PPE)

PPE provides a protective barrier between the hazard and the employee. If the PPE device fails or is improperly used, the employee will be directly exposed to the hazard. PPE remains the "last line of defense" and needs to be used properly and in accordance with established standards (Langin *et al.,* 2010). To manage PPE correctly it is critical to ensure the following: use the most suitable PPE for each hazard, supply PPE to employees, provide training on how to correctly use PPE, and monitor PPE use. PPE consist of the following lists (Photo 16-5):

Head protection: wear approved safety hard hat or helmet of a color that contrasts with the work environment. Secure the chin strap when working.

Photo 16-5 Personal Protective Equipment. (PPE)

Eye and face protection: wear safety eyewear with a face shield to protect eyes from floating debris. When using chainsaws, wear safety eyewear with a face shield which easily flips up if not required.

Hearing protection: wear earmuffs or earplugs when exposed to high noise levels, for example, when using a chainsaw or around noisy equipment.

Clothing: dress appropriately for anticipated weather conditions. Remove any dangling jewelry to avoid getting snagged on equipment or branches. Wear comfortable close-fitting clothing that does not restrict the ability to move freely.

High visibility apparel: wear high visibility clothing in a color that contrasts with the environment so it can be seen at a distance. Make sure that high-visibility clothing is not covered by other clothes. It must be worn when working around any moving vehicles, equipment or lines, working alone or in isolation, harvesting trees at night, performing traffic control in work areas where there is vehicle traffic moving through a work zone or for falling operations. Loose-fitting high-visibility outer clothing must be "tear-away" if worn for work where it could get caught on moving equipment or objects like branches.

Hand protection: wear gloves that fit and grip well to protect against cuts, abrasions, splinters, vibrations, wet, damaging vegetation, and when filling and handling the chainsaw, and when handling wire, rope, or other steel objects.

Leg protection: when operating a chainsaw, leg protection must be worn like pants, chaps, or an apron made of cut-resistant material. Check that the leg protection has a label indicating it meets work safety standards. Check that the cut-resistant material protects the front and sides of legs. Make sure that clothes stay in position while working so the cut-resistant material provides protection. Leg protection should be comfortable enough and fit with each person to avoid a safety risk.

Foot protection: wear approved safety footwear to protect ankles, soles, and toes. Wear chainsaw protective footwear when working with a chainsaw. Wear caulked or other equally effective safety footwear when walking on logs, poles, pilling, or other round timbers.

Selecting an Appropriate Forest Harvesting System

An appropriate harvesting system for a forest seeks to balance environmental, social and economic interests in undertaking harvesting in that forest. In recent years some studies have been published to estimate best suitable harvesting systems for specific forest districts or compartments using GIS that take ecological and social criteria into account for a comprehensive analysis of the impacts of harvesting operations (Kuhmaier & Stampfer, 2010). However, the selection of suitable logging systems via GIS application requires skilled operators and can be rather complicated for adoption by local farmers or foresters who do not have basic knowledge of GIS. A study conducted to devise a simpler method for selecting the appropriate logging system as a part of Sustainable Forest Operations (SFO) is presented here.

The study, which was carried out in Teak plantations in Phrae province of northern Thailand, applied the Delphi method to identify the balance between environmental, social and economic aspects (Table 16-1). A total of 22 forest plantation staffs were asked to give weightage to these aspects among the choices placed before them. The grading score from each factor is combined with weight score for each tools/machine and summed up for each logging system. The logging system that obtained the highest score is considered the best logging system in the given circumstances.

Table 16-1 Reclassification of grading score for each relevant factors

Aspect	Grading score				
	1	**2**	**3**	**4**	**5**
	Critical	Unacceptable	Fair	Good	Excellent
Productivity	<5.99 m^3/h	6-10.99 m^3/h	11-15.99 m^3/h	16-20.99 m^3/h	>20.99 m^3/h
Logging cost	>900 BTH/m^3	650-900 BTH/m^3	450-649 BTH/m^3	150-449 BTH/m^3	<150 BTH/m^3
Heart rate	>80 bpm	76-80 bpm	72-75 bpm	69-71 bpm	<69 bpm
Working posture	>= 11	8.0-10.9	4.0-7.9	2.0-3.9	<2
Soil compaction	>1.8 g/cm^3	1.6-1.8 g/cm^3	1.4-1.6 g/cm^3	1.2-1.4 g/cm^3	<1.2 g/cm^3
Soil erosion	> 9.6 mm/y	7.21-9.60 mm/y	2.41-7.20 mm/y	0.96-2.40 mm/y	<0.96 mm/y

The recommended logging system which got the highest score was felling by chainsaw, extraction by elephant together with farm tractor, and transport by truck with loader. The findings can assist forest managers in selecting the right harvesting system taking into account the environmental, economic and social aspects. It is a relatively simple tool for forest manager to help in making decision.

Appropriate Harvesting Technology

Appropriate technology for teak harvesting in Thailand would be one that suits small-scale operations, affordable by locals, decentralized, labor-intensive, energy-efficient, environmentally sound, and locally autonomous. When a machine or a combination of machines is selected, care must be taken to introduce harvesting systems and techniques which are appropriate under the given circumstances. A system can be considered appropriate if all the various needs, possibilities and limitations have been taken into consideration. The level of technology adopted should take into account availability of both funds and skills with the project (Heinrich, 1987).

In developing countries manual and semi-mechanized logging operations still persist in most instances on account of 1) plentiful availability of cheap labor, 2) difficulties in importing high tech equipment, 3) limited availability of funds for forestry activities, 4) difficulties in access to spare parts, 5) shortage of skilled machine operators and technicians, and 6) lack of maintenance and repair facilities for equipment and advanced machinery.

Lessons Learned and Recommendations

Forest harvesting carries not only physical risks to the harvesting workers but can also cause severe environmental impacts if implemented without forethought and proper planning. Hence carefully plan and supervision during implementation is very crucial part of harvesting operation. Improvement of existing labor-intensive methods through better organization of work, use of more efficient hand tools, equipment and working methods, and training of personnel in the planning and application of appropriate logging technology may help improve logging operations in the short and medium term while in the long term greater reliance on modern technologies should be aimed at.

Conclusion

Harvesting and extraction operations are the activities that generally cause the most significant impacts on forest and environments in forestry. The impact of harvesting and extraction can be reduced through proper planning and control of harvesting operations using sound principles, systems, and techniques that have stood the test of time. Successful harvesting should be 1) technically feasible considering physical limitations, engineering knowledge, and environmental relationship of the forest, 2) economically viable considering the costs and benefit of short- and long-range consequences, 3) environmentally sound considering impacts on the natural and social environment, and 4) institutionally feasible considering laws and regulations, landowner objectives, and social values.

References

Applegate, G., Putz, F. E. & Snook, L. K. (2004). *Who Pays for and Who Benefits from Improved Timber Harvesting Practices in the Tropics? Lessons Learned and Information Gaps*. Center for International Forestry Research, Bogor, Indonesia.

Dykstra, D. P. & Heinrich, R. (1992). Sustaining tropical forests through environmentally sound harvesting practices. *Unasylva,* 169, 9-15.

Dykstra D. P. & Heinrich, R. (1996). *FAO model code of forest harvesting practice*. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO (Food and Agriculture Organization) (1999). *Code of Practice for Forest Harvesting in Asia-Pacific*. RAP Publication: 1999/12, Bangkok, Thailand.

Heinrich, R. (1987). Appropriate forest operations. In: *Proceedings of FAO/Finlan Training Course Philippines*. FTP publications: forest harvesting no.24.

ITTO (The International Tropical Timber Organization) (n.d.). *Reduced Impact Logging*. https://www.itto.int/sustainable_forest_management/logging/. (accessed 29 August 2021).

Kaakkurivaara, N. & Stampfer, K. (2018). Assessment for Improvement: Harvesting Operations in Small-Scale Forest on Thai Steep Terrain. *Small-scale Forestry,* 17, 259-27.

Klassen, A. (2011). *Planning considerations for Reduced Impact Logging*. Technical Procedures Manual under project: ITTO PD 110/01 REV.4 (I): "Program to facilitate and promote adoption of reduced impact logging (RIL) in Indonesia and the Asia Pacific region"

Kuhmaier, M. & Stampfer, K. (2010). Development of a Multi-Attribute Spatial Decision Support System in Selecting Timber Harvesting Systems. *Croatian Journal of Forest Engineering,* 32(2), 75-88.

Langin, D., Ackerman, P., Krieg, B., Immelmann, A., Potgieter, C., Rooyen, J. et al. (2010). *South African Ground Based Harvesting Handbook*. Institute for Commercial Forestry Research, Pietermaritzburg, South Africa.

Rianthakool, L., Kaakkurivaara, N., Diloksumpun, P. & Arunpraparut, W. (2018). Supply Chain Operations in Teak Plantation. In: *Proceedings of 6th International Forest Engineering Conference (FEC2018)*, Rotorua, New Zealand.

Chapter 17: Teak Small Holder Plantations in Indonesia for Improving Livelihood

Anis Fauzi and Anto Rimbawanto

Abstract

Teak small holder plantation is an important source of timber in Indonesia as well as in other tropical countries in Africa, South and Central America. Over 1.5 million small-holder farmers in Java, Indonesia, manage nearly half a million hectares of tree-based agroforestry systems, with teak being the most common tree crop. The small to medium scale industry in Java receives up to 80% of small-diameter logs (less than 30 cm dbh) from smallholder plantations. Small holder plantations have the potential to produce up to 8.2 million m3 of teak per year. Teak from small-holder plantations is widely used in Indonesia's furniture industry, therefore the future of small-holder teak plantations looks bright. If farmers have access to and are willing to plant high-quality planting materials, apply proper silviculture techniques, and participate under a cooperative system, their economic gains can be maximized.

Introduction

Teak plantations have been established in at least 43 countries with total area of around 6.8 Mha, representing a theoretical capacity to produce up to 30 Mm3 of wood annually (Midgley et al., 2015). Most of these plantations are in Asia, with the largest areas being in India, Indonesia, and Myanmar (Roshetko et al., 2013). Smallholder plantings, despite their small size, contribute significantly, accounting for 19% of the area in Africa and Asia, and 31% and 34% in Central and South America, respectively (Kollert & Cherubini, 2012).

Is teak native to Indonesia? Some reports have stated that teak was naturalized in Java since centuries ago and has been acclimatized to local conditions and has regenerated naturally throughout the area (Kaosa-ard, 1999; Verhaegen et al., 2010). Today, teak has been planted in many parts of Indonesia, in addition to the long existing teak plantation on Java, mainly as small holder plantations. No major plantations outside Java have been reported.

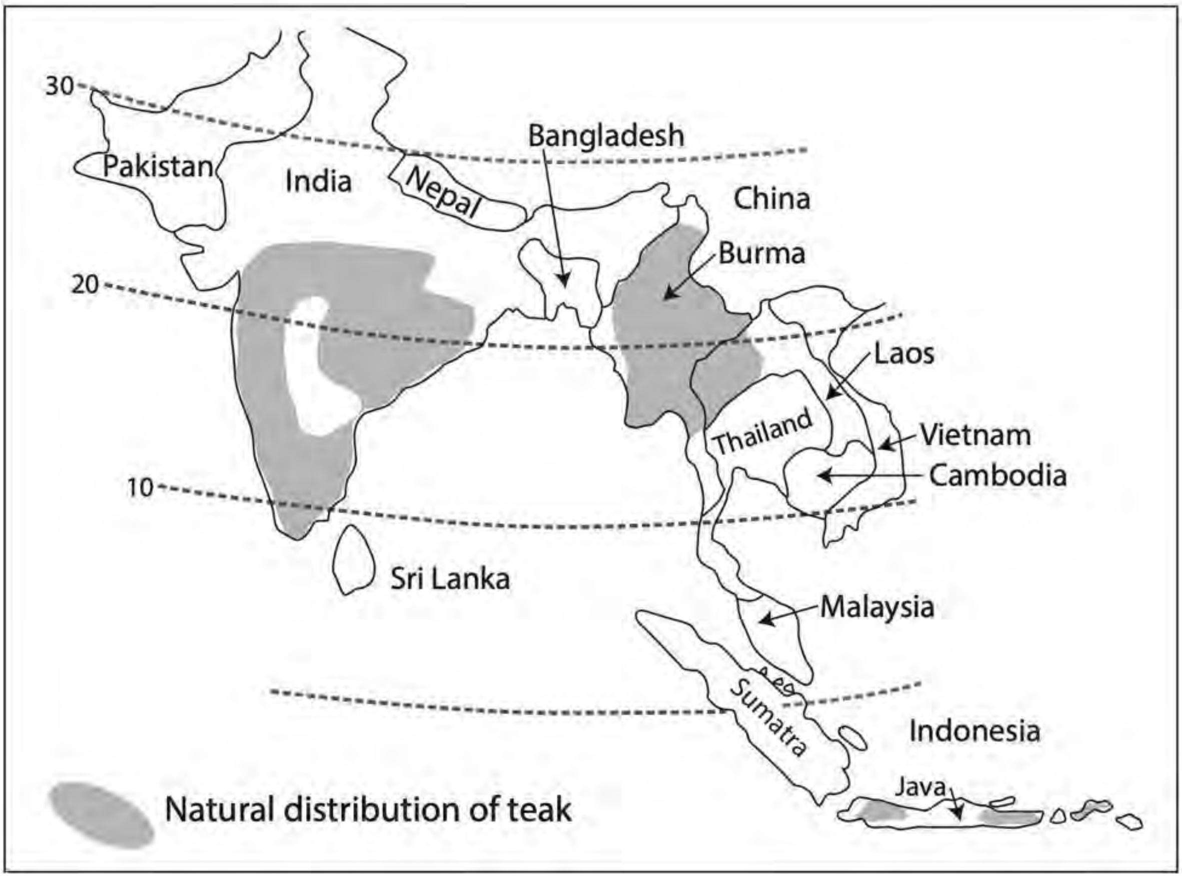


Figure 17-1 Natural distribution of teak
Source: Midgley et al. (2015)

Community forestry or smallholder plantation, as defined by Gilmour & Fisher (1991), is the control and management of forest resources by rural people who use them for domestic purposes and as an integrated element of their farming systems. Small-holder plantation's social and biophysical components are equally essential. Smallholder plantation management has been done in the tropics for over a century and is an important part of forest management.

In Java, 1.5 million smallholder farmers manage 444,000 hectares of tree-based agroforestry systems, with teak being the most common tree crop (Roshetko et al., 2013). Teak is one component of multispecies, tree-based systems in another 800,000 ha of smallholder agroforestry in various parts of Indonesia. Small-holder teak has become an important source of timber for furniture industry in Java. Studies found that, small-diameter logs (less than 30 cm dbh) supplied by smallholder farmers account for 80% of the teak utilized by small to medium producers (Achdiawan & Puntodewo, 2011).

Photo 17-1 Intercropping of maize in teak plantation on Java (Credit: A. Rimbawanto)

Teak Small Holder Plantation

What is teak small holder plantation

The term "small holder plantation" became popular in Indonesia in the mid-1970s, when the government encouraged communities on the island of Java to plant trees in forests and open areas as part of the Afforestation and Greening National Program. The Forestry Law No. 5 of 1967 established a legal definition of small holder plantation, which was later updated by the Law of Forestry No. 41 of 1999. Furthermore, small holder plantation are defined as forest belonging to people with holdings of at least 0.25 ha planted with tree species and or other plants of more than 50% and or trees of around 500 stems in an area of 1 ha.

Small holder plantations have the following characteristics (Hindra, 2006; Purnomo et al., 2010):

- Apart from timber, small holder plantation also produces other crops such as flowers, fruit, bark, leaves, rhizomes, spices, seasonings, forage for livestock, fungi and so forth.
- Trees are harvested by selective logging or as needed.
- Regeneration can be done in a natural way using seeds are available to the people, or it can be done artificially by purchasing seed from a seed merchant.
- The area of plantation for each family head is small, ranging from 0.2 to 1.0 hectares, and is determined by their ownership status. If owned by a group, the land can be as large as 20 hectares or more.
- The planting pattern is made up of several types of trees, plant food, and grass. This is accomplished by utilising a small area to cover a variety of needs (food, wood, vegetables, forage for livestock).

- The management systems depend on land owners

Pure plantation (monoculture), a mixture (polyculture), and agroforestry are the three types of small holder plantations based on the types of plants that grow. Because the land is far from home and there is limited labour to cultivate it, planting tree species is preferable as it does not require regular tending. Furthermore, often the land is not ideal for cash crops or fruit crops. A variety of tree species are planted in mixed plantations. Trees can be chosen based on their maturity age as well as their ability to grow in the shade. On the other hand, agroforestry (intercropping) is a system of plantation that combines cash crops/perennial crops with tree species. The agroforestry system has long been known to people who have a small acreage, so that the small land area can provide some form of crop to satisfy their demands. The planting pattern selected will allow people to grow maize and beans in between teak trees at age 1-3 years, or planting elephant grass or pineapple in between albizia trees.

Photo 17-2 Patterns of agroforestry in a small holder plantation in Nglanggeran, Gunung Kidul (Credit: A. Fauzi)

Teak small holder plantations in Indonesia started to evolve in the 1950s, following a program known as "karang kitri," which refers to planting trees around the house. Then, around the 1960s and 1970s, began a nationwide reforestation and afforestation campaign. Under the National Afforestation and Greening Programs, seedlings of albizia (*Falcataria mollucana*), acacia (*Acacia auriculformis*), mahogany (*Swietenia macrophylla*), rosewood (*Dalbergia latifolia*), and teak (*Tectona grandis*) are provided free of charge to the public.

Farmers were first sceptical about planting trees because harvesting trees takes years. However, as time goes, the short (5-year) cycle of some trees, such as albizia and acacia, earns a place in the hearts of the farmers. Teak is not commonly planted because of its long-life cycle (30-40 years). Yet, in the mid-1980s some farmers were harvesting albizia and teak, and selling the woods. This has renewed interest in the community in planting timber species, particularly albizia and teak. Teak is a species that grow best in soil with high calcium, therefore, it's ideal for development in Java. Teak has become more popular because of high demand and better price.

In Yogyakarta, the growth of small-holder plantations is encouraging both in term of potential or land cover. According to data of 2019 (Anonymous, 2019), the province of Yogyakarta has a total of 78,400ha of small holder plantation scattered across several districts, including Gunung Kidul 44,110ha, Bantul 8,595ha, Sleman 4,898ha, and Kulonprogro 20,795ha.

Perhutani manages the teak forest in Java, which covers around 1.0 million hectares (Perhutani, 2018). The plantation is divided into three regional forest management units, each representing one of Java's three provinces. Region I manages teak plantation in Central Jawa, Region II in East Jawa and Region III in West Jawa. Teak is the dominant species, with other species such as pine (*Pinus merkusii*), mahogany (*Swietenia macrophylla*), albizia (*Falcataria mollucana*) kayuputih (*Melaleuca cajuputi*), and others serving as complementing species.

Outside of the Perhutani area, teak is being planted as small holder plantation across Java, in Lampung, Konawe, the island of Muna, and Buton (Southeast Sulawesi), South Sulawesi, West Nusa Tenggara, and East Nusa Tenggara.

Photo 17-3 Teak small holder plantation in Muna, South-east Sulawesi (Credit: A. Rimbawanto)

Potential of teak small holder plantation

The establishment of teak small holder plantations began following rampant illegal logging in teak plantations of Perhutani around 1997-2000, that resulted in a decline in potential teak production. Teak from the Southeast Sulawesi Islands of Muna and Buton was used to fulfil industry demand. Mass illegal logging has changed the distribution of age class in teak forests in Java, in addition to lowering the potential of teak forests. In the past, Java's teak woods were dominated by age class IV (40 years) and V (50 years), but soon after, it was dominated by age class I (10 years), II (10 years) and III (20 years)

Sukadaryati (2006) reported small holder plantations have a potential to produce 39.5 million m3 with an area of 1.5 million ha, with total number of trees roughly 262 million, and 74 million trees are ready for harvesting. The composition and distribution of the number of species being planted in the small holder plantations is shown in Table 17-1 as follows:

Table 17-1 The population of planted species in the small holder plantation in Indonesia

No	Tree species	Potential (million. stem)		Number of tree (million)	Harvestable (million)
		Java	Outside Java		
1	Acacia (*Acacia* sp.)	22.61	9.41	32.02	12.07
2	Bamboo (*Bambusa sp*)	29.14	8.79	37.93	6.72
3	Teak (*Tectona grandis*)	50.12	29.59	79.71	18.45
4	Mahogany (*Swietenia macrophyl la*)	39.99	5.27	45.26	9.50
5	Pine (Pinus merkusii)	3.52	2.30	5.82	2.71
6	Albizia (*Falcataria molluccana*)	50.07	9.76	59.83	24.62
7	Sonokeling (*Dalbergia latifolia*)	2.01	0.34	2.35	0.74
	Total	197.46	65.46	262.93	74.81

Source: Sukadaryati (2006)

Teak is most widely planted accounted for 62.87% in Java and 37.12% planted outside Java. Second preferred species is albizia (*Falcataria molluccana*) of which 83.36% is grown in Java and 16.30% planted outside Java, third is mahogany (*Swietenia macrophylla*) of which 88.35% is grown in Java and 11.64% planted outside Java.

Assuming that the volume of 1 trees is 0.25 m3, then total volume of wood from small holder plantation is = 0.25 m3 x 262,929,193 = 65,732,298.25 m3. If the average cutting cycle is 8 years old, total timber production from small holder plantation of 8.2 million m3 / year.

Wood production from small holder plantation should be based on the potential that is available. Production target that exceeds the ability of production will cause a drop in the potential of the plantation that can lead the unsustainable management of the plantation. The parameters used to determine the potential of the forest people is acreage (ha), timber volume (m3) and the number of trees (Hindra, 2006).

In Indonesia, approximately 61.6 % of small holder forests are self-funded, while 38.4 % receive government subsidies or funding. Several schemes of subsidies, such as Credit Enterprises Forest People, the forest people of DAK DR (Fund Allocation Special Fund Reforestation), and the forest people of Program GERHAN, are used to develop small holder plantation schemes (Hindra, 2006). The success of self-funded small holder forests demonstrates that community aware of the economic, ecological, and socio-cultural benefits of small holder plantation.

What can be improved

There are a number issues with small holder forest management, including production, processing, marketing, and institutional issues (Darusman & Hardjanto, 2006; Purnomo et al., 2010; Roshetko et al., 2013).

a. Production

Production issues covering aspects of silviculture of teak, source of seeds, harvesting and sales. Most of the teak farmers have not applied optimal intensive silviculture. Standard silvicultural practices such as the use of good sources of seeds, fertilizing, thinning, pruning and pests/diseases control have not been carried. This has resulted in low productivity of the plantation and the low quality of the logs. Because teak is farmer's main income sources, inputs for silvicultural management is fairly low. To improve teak growth and quality, skilled extension officers need to motivate and advise them in appropriate silvicultural techniques.

b. Processing

Most farmers sell the wood as a raw material/logs. Farmers usually sell when the tree is still standing, while the industry wants the wood already in the form of sortie of specified sizes. Hence the added value wood fall over in the hands of traders or intermediary (middle man) and the collectors of wood rather than the farmers themselves. Farmers could form a cooperative which operate a basic saw mill that process the log into marketable sizes. This way farmers may get increased added value and better price of the timber.

c. Marketing problems

Timber from small holder plantations are generally of low quality because the quality of seedling being planted was low and there is lack of intensive cultivation. As a result, the price of wood is usually lower than the price of teak wood produced by Perhutani. In reality, with ever-increasing innovations in timber processing techniques, faulty wood and low-quality teak can be remedied using techniques such as wood drying, wood preservation, staining, and other approaches. Teak farmers encounter a number of challenges when it comes to marketing their product, including a lack of information about the price of wood, a lack of negotiation capability, and inadequate bargaining power.

d. Institutional issues

Farmers sell the timber directly to the merchant or intermediaries that exist around the village. Farmers are forced to sell teak wood before it is mature to harvest for a number of reasons, and as a result, they are unable to obtain a fair price. This individual selling is unfavourable to farmers. They can have a better bargaining position and get a higher price if they sell through a cooperative. Unfortunately, due to financial constraints and a lack of capacity to carry out cooperative activities in a professional manner, not all farmers prefer to sell as a group.

Teak Genetic Resources of Small Holder Plantations

There is no doubt that genetic quality of seeds plays vital role in ensuring the quality of the plantations and the timber they produce. Series of tree improvement activities had been implemented to improve the genetic quality of teak in Java. First provenance trial established in 1932, screening 12 geographical origins. Study in 1958 concluded that Malabar, Pati, Cepu and Ponorogo were best suited (Daryadi, 1959). Comprehensive genetic improvement program launched in 1981, including selection of plus trees, establishing clone bank and clonal seed orchard. Over 680 plus trees were selected. Cloned plus trees were planted in clonal bank for safe keeping, and clonal seed orchard was established for seed production (Wirjodarmodjo & Subroto, 1983).

Currently, most of the large commercial plantations use elite planting materials, either as seed or clones. Unfortunately, while the role and potential of smallholder teak systems are positive, there are some major barriers, the most notable of which is availability to better genetic planting materials. Because better planting material was expensive and not widely available, most smallholders plant wildings or other local germplasm. Furthermore, farmers' poor understanding of what constituted good quality teak trees also contributes to farmers reluctant to use better seed. Commercial planting stock material that is vegetatively propagated by shoot cutting, or locally known as Jati Unggul Nusantara (JUN), has become available to the public in recent years. JUN as it is normally called, is harvestable at year 6-8 with diameter of around 30 cm. This local clone is promising and offer small-holder farmers to improve the quality and productivity of their teak plantation (Supriono & Setyaningsih, 2012).

Photo 17-4 An 8-year-old plantation of JUN at Gunung Kidul Yogyakarta (Credit: A. Rimbawanto)

Recent study found that the management of small holder teak forests is generally carried out in a traditional manner, so that the quality and quantity of wood produced is still low (Pramono et al., 2010). Good silvicultural practices such as pruning, and thinning are not practiced. Smallholder teak systems were classified as overstocked, slow growing, and of sub-optimal quality and production due to smallholders' typical management techniques, which reduced the productivity of their systems (Roshetko & Manurung, 2009).

Economic Benefit of Teak Small holder Plantation

The benefit of small holder plantation to farmers' livelihood

In terms of coverage and earnings received by farmers, the expansion of small holder plantations in Indonesia indicates a good trend. According to a study conducted in Gunung Kidul, small-holder plantation income accounted for 12 percent of total income (Roshetko et. al, 2013). Even though it isn't much, it does make a difference for the farmers.

Incomes of farmers

On the Indonesian island of Java, teak growers' income varied. The degree of income disparity is influenced by the type of crop, the level of need, and the socio-cultural conditions that exist in a society. According to Roshetko et al. (2013), annual income ranged from Rp. 0 to Rp. 58.000. 000, -, with an average income of less than Rp. 10,000,000, - (US$ 1125). The study also found that 40 percent of their income are earned from intercropping, 25 percent from cash crop and animal husbandry, 12 percent from teak, and 3% from cultivation of other crops. Although teak give a contribution around 12%, teak is an important species in the community. Farmers regarded planting teak is as a saving. The tree will be harvested when they needs large sum of funds such as for their children's further education, marriage, pilgrimage, or medical expenses.

To give you an idea how much revenue net farmer forest people's identity, given an overview of cases in the Province of DIY in order to provide estimates. In the exploitation of forest people either in the form of moor or yard, give contribution income home household farmers fairly high and varied. Parameter economy which is used among other things:

1). Net profit, which is expressed by the value of the NPV (Net Present Value) by using the rate of interest of 7.5% / year, calculated based on rate interest loans and inflation.

2). B / C ratio.

3). Average net income per year expressed as AEV (Annual Equivalent Value).

Details are as follows (BPKH, 2007)

1. Meadow pattern 1 (full trees)

No	District	NPV (Rp./ ha / cycle)	AEV (Rp/ha/ year)	B/C Ratio
1	Bantul	287,377 - 1,838,964	28,275 - 165,555	1.02 - 1.12
2	Gunungkidul	1,609,612 - 7,936,746	158,371 - 780,903	1.11 - 2.05
3	Kulon Progo	2,912,510 - 5,210,715	262.201 - 512.686	1.22 - 1.43
4	Sleman	267,633 - 8,712,400	24,094 - 784,340	1.05 -1.75

2. Meadow pattern 2 (mix planting)

No	District	NPV (Rp./ ha / cycle)	AEV (Rp/ha/ year)	B/C Ratio
1	Bantul	383,347 - 423,868	37,718 - 38,1605	1.02
2	Gunungkidul	834,315 - 4,849,545	82,089 - 477,151	0.95 – 1.37
3	Kulon Progo	3,529.068 – 9,110.290	347,228 - 820,160	1.2 9 - 1.35
4	Sleman	1,762,927 – 3,120,904	2,800,961 - 158,709	0.61 -1.07

3. Garden

No	District	NPV (Rp./ ha / cycle)	AEV (Rp/ha/ year)	B/C Ratio
1	Bantul	447,548 - 19,143,115	40,290 - 1,883,506	1.02 - 1.89
2	Gunungkidul	18,341,230	1,804,608	2.49
3	Kulon Progo	15,961,453 - 19,087,578	1,436,940 – 18,788,042	1.76 – 2.07
4	Sleman	6,866 ,086 – 19,897,135	618,124 - 1,791,253	1.48 – 2.79

In all districts, the NPV, AEV, and B/C ratio are calculated using teak prices, except in Sleman, where albizia timber is used. The NPV of three types of small holder plantations ranges from Rp.267.633 to Rp. 19,897,135/ha/cycle, whereas the AEV is between Rp. 24,094 and Rp. 1,878,042/ha/year. Small holder plantation is a profitable business as the B/C ratio is greater than one.

Conclusion

Demand for teak for manufacture of indoor and outdoor furniture, building construction including architectural finishes such as windows, doors, flooring and decking, and boat building will continue to grow in line with the global economic growth. As supply of native teak from Myanmar, India and Indonesia is diminishing, teak from plantations is the best option to meet the demand. The future of small holder teak plantation is potentially promising as teak from small-holder plantations is widely used in Indonesia's furniture industry. Farmers' economic benefits can be maximized if they have access to and are willing to plant high-quality planting materials, use appropriate silviculture techniques, and collaborate under a cooperative scheme.

References

Anonymous. (2019). *Book on Forestry Statistics*. Department of the Environment and Forestry Provincial Service of Yogyakarta, Indonesia.

Achdiawan, R. & Puntodewo, A. (2011). *Livelihood of furniture producers in Jepara*. Unpublished Project Report: mahogany and teak furniture: action research to improve value chain efficiency and enhance livelihoods (FST/2007/119). Australian Centre for International Agricultural Research, Canberra, Australia.

BPKH (2007). *Portrait of the Forest of the Special Region of Yogyakarta*. BPKH (Forest Area Consolidation Center) Region XI Java - Madura, Yogyakarta.

Daryadi, L. (1959). Penyelidikan seleksi jati (*Tectona grandis*), Pengumuman No.70 Lembaga Penelitian Hutan, Bogor, Indonesia.

Darusman, D. & Hardjanto, H. (2006). *Tinjauan Ekonomi Hutan Rakyat*. Prosiding Seminar Hasil Penelitian Hasil Hutan 2006: 4-13. Fakultas Kehutanan, IPB, Bogor, Indonesia.

Gilmour, D. A. & Fisher, R. J. (1991) *Villagers, Forest and Foresters: The Philosophy, Process and Practice of*

Community Forestry in Nepal. Kathmandu Sahayogi, Nepal.

Hindra, B. (2006). *Potential and institutional community forests, Proceedings of Seminars on Forest Products*. Research and Development Center for Forest Social and Economics, Bogor, Indonesia.

Kaosa-ard, A. (1999). Gains from provenance selection. In *Proceeding of International Seminar on Site, Technology and Productivity of Teak Plantations*, pp. 191-207. 26-29 January 1999, Chiang Mai, Thailand.

Kollert, W. & Cherubini, L. (2012). *Teak resources and market assessment 2010* (*Tectona grandis Linn.* f). Food and Agriculture Organization, Rome, Italy.

Midgley, S., Somaiya, R. T., Stevens, P. R., Brown, A., Kien, N. D. & Laity, R. (2015). *Planted teak: global production and markets, with reference to Solomon Islands*. ACIAR Technical Reports No. 85. Australian Centre for International Agricultural Research, Canberra, Australian.

Pramono, A. A., Fauzi, M. A., Widyani, N., Heriansyah, I. & Roshetko, J. M. (2010). *Pengelolaan Hutan Jati Rakyat: Panduan Lapangan untuk Petani*. CIFOR, Bogor, Indonesia.

Perhutani, P. (2018). *Statistik Perum Perhutani tahun 2012-2016*. Perum Perhutani, Jakarta, Indonesia.

Roshetko, J. M. & Manurung, G. E. S. (2009). *Smallholder teak production systems in Gunung Kidul Indonesia*. The 2nd World Congress of Agroforestry, Agroforestry the Future of Global Land Use. 24-29 August 2009. Nairobi, Kenya.

Roshetko, J. M., Rohadi, D., Perdana, A., Sabastian, G., Nuryartono, N., Pramono, A. A. et al. (2013). Teak agroforestry systems for livelihood enhancement, industrial timber production, and environmental rehabilitation. *Forests, Trees and Livelihoods*, 22(4), 241-256.

Sukadaryati, S. (2006). *The Potential of Community Forests in Indonesia and Its Problems*. Proceedings of the R&D seminar on Forest Products, Bogor, West Java, Indonesia.

Supriono, B. & Setyaningsih, L. (2012). Growth of Superior Teak Plant Nusantara with Agroforestry Pattern at Five Years Old. *Jurnal Sains Natural Universitas Nusa Bangsa, 2*(2), 179 – 185.

Verhaegen, D., Fofana, I. J., Logossa, Z. A., & Ofori, D. (2010). What is the genetic origin of teak (*Tectona grandis* L.) introduced in Africa and in Indonesia? *Tree Genetics & Genomes,* 6, 717–733.

Wirjodarmodjo, H & Subroto, P. M. (1983). *Teak Improvement by Perum Perhutani*. Duta Rimba 83-64/IX :3-13. Jakarta, Indones

Chapter 18: Carbon Sequestration and Carbon Credits of Teak Plantations

S. Sankar

Abstract

Teak is an important high value timber species widely planted in the tropics in many South-east Asian, African and Latin American countries. In Kerala, India, it is the most important revenue earning plantation species on a 50-to-60-year long rotation. Being an efficient sequester of carbon, it can play an additional role in combating global warming through sustainable forestry projects. Further, the wood being long-lasting even after cutting through various products, teak is a good choice for receiving carbon credits. This paper highlights the study conducted in the teak plantations of Kerala on the carbon storage in different compartments of teak at different thinning regimes and final felling at 50 years rotation period alongside it utilising for carbon credits.

Introduction

Teak (*Tectona grandis* Linn. F.) is a valuable timber yielding species in the tropics especially India, Indonesia, Malaysia, Myanmar, northern Thailand, and north-western Laos. The first teak plantation in the world was raised in Nilambur, Kerala, India in the year 1840. The Kerala Forest Department now has about 56,510 ha under teak, out of which approximately 64 percent is in the first rotation and the remaining 36 percent in the second and third rotation stages and about 1000 ha is being felled and replanted every year (Balagopalan et al., 2005). Hence raising and managing teak plantations in suitable areas can be eligible not only for producing useful hardwood but also for sequestering carbon from the atmosphere to reduce global warming (Muralidharan & Sharma, 2003).

This paper attempts to discuss carbon sequestration by teak plantations and possibilities of using this to create carbon credits. The examples are from teak plantations raised and managed by the Kerala Forest Department in India. To receive credits for the carbon sequestered by afforestation or reforestation, one has to understand the process of Clean Development Mechanism.

Clean Development Mechanism

The Clean Development Mechanism (CDM), defined in Article 12 of the Protocol, allows a country with an emission-reduction or emission-limitation commitment under the Kyoto Protocol (Annex B Party) to implement an emission-reduction project in developing countries.

A carbon credit is a generic term for any tradable certificate or permit representing the right to emit one ton of carbon dioxide or the equivalent amount of a different greenhouse gas (tCO2 e). One carbon credit is equal to one ton of carbon dioxide, or in some markets carbon dioxide equivalent. Certified Emission Reductions (CERs) are a type of emissions unit (or carbon credits) issued by the Clean Development Mechanism (CDM) Executive Board for emission reductions achieved by CDM projects and verified by a DOE (Designated Operational Entity) under the rules of the Kyoto Protocol.

An afforestation or reforestation measure, operation or action that aims to achieve net anthropogenic GHG removals by sinks, whether as a whole project or as a part of a project. The direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or human-induced promotion of natural seed sources.

Carbon sequestration

Carbon sequestration is the process by which atmospheric carbon dioxide is taken up by trees, grasses, and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliage, and roots) and soils. The sink of carbon sequestration in forests and wood products helps to offset sources of carbon dioxide to the atmosphere, such as deforestation, forest fires, and fossil fuel emissions. Global warming due to green house gases is a matter of great concern today and CO_2 accounts for 64% of the increase in heat. CO_2 in the atmosphere has increased from 270 ppm before industrial revolution to 401.03 ppm by September 2016 (Mauna Loa observatory, USA). Discussions to reduce the GHGs started with the Stockholm Conference in 1972. Kyoto Protocol (KP) 1997 imposed legally binding commitments for emission reduction to that of 1990 levels by the Annex 1 countries (developed countries).

Flexibility mechanisms suggested to achieve the same were:
1. Emission Trading
2. Joint Implementation
3. Clean Development Mechanism

United Nations Framework Convention on Climate Change (UNFCCC, 2011) included Afforestation and Reforestation (A/R) as an effective way to reduce atmospheric carbon as part of CDM. Certified Emission Reductions (CERs) provide an opportunity to claim compensation for such efforts.

Carbon sequestration is the long-term storage of atmospheric carbon dioxide in different sinks such as biomass, soil, ocean, rocks, etc., in such a manner that it is not re-emitted into the atmosphere in the near future. Because of their project-based character, CDM can assist project developers in enhancing the economics of their project by selling the resulting emission reductions. Not every project is eligible as a CDM project; this is subject to a number of activities and approvals. Below is a list of some typical projects that may be eligible:

- The implementation of a renewable energy project, e.g., wind, or biomass;
- Demand-side energy efficiency improvement, e.g., implementation of energy saving light bulbs;
- The reduction of methane emissions from a landfill site;
- Reduction of industrial process emissions;
- Forestry practices to store carbon.

The contribution by forest in carbon sequestration is commendable. India with 69.2 million hectares forest cover (FSI, 2013) including a wide range of forest types from wet to dry forest in temperate to tropical climate has high capacity in absorbing and retaining carbon. Carbon is distributed in the landscape in:

- Aboveground biomass
- Belowground biomass
- Litter
- Dead wood
- Soil organic matter

Carbon is stored in harvested wood, wood products and dead organic matter. 195 million tons of carbon was reported to be stored in harvested wood products in the household sector and 62 million tons locked in commercial sector.24 million tons of carbon is being locked annually in harvested wood products (FSI, 2013). But still carbon is always stored more efficiently in forest stands than in wood products.

Carbon sequestration by Teak

An area of 2.4 million ha of teak in the world would have the potential to sequester 240 million tons of carbon. It is reported in 2015 that an average carbon accumulation of 532 kg C m^{-2} yr^{-1} in teak across the mono and multi-specific stands. Carbon storage by teak increases with age of the plantation from 51.32 t ha^{-1} in 19 year-old plantations to 101.40 t ha^{-1} in 33 year-old teak plantations. An average above ground carbon storage of 2.9 Mg ha^{-1} in the first year to 40.7 Mg ha^{-1} in the 10^{th} year of teak plantation in Western

Panama. Carbon sequestration potential has been found to increase with high input management. It has been reported that there has been an improvement in carbon sequestration from 0.816 Mg ha^{-1} without any management to 1.76 Mg ha^{-1} with high input management in 5 year old teak plantations. The average carbon stocks of 55.9 MgC ha−1, and the remaining carbon in harvested wood products (HWPs) at final felling was 41.7 MgC ha−1 of the first management cycle. When three management cycles are considered, the average carbon stocks in the standing plantations were 60.5 MgC ha−1, 42% of which are stored in the HWPs in Thailand.

Carbon sequestration by Teak Plantations in Kerala, India

Teak plantations in different thinning regimes and at final felling were surveyed in Nilambur forest division, Kerala and seven sites corresponding to the prescribed felling schedule and on comparable site quality were selected for the study.

Growth of Teak in plantations

Height of teak trees is given in Figure 18-1. Teak height varied from 6.93 m at age of five years to 22.83 m at 50 years. Diameter at breast height also increased with age from 6.36 cm to 45.01 cm from 5th year to 50th year respectively. (Figure 18-2)

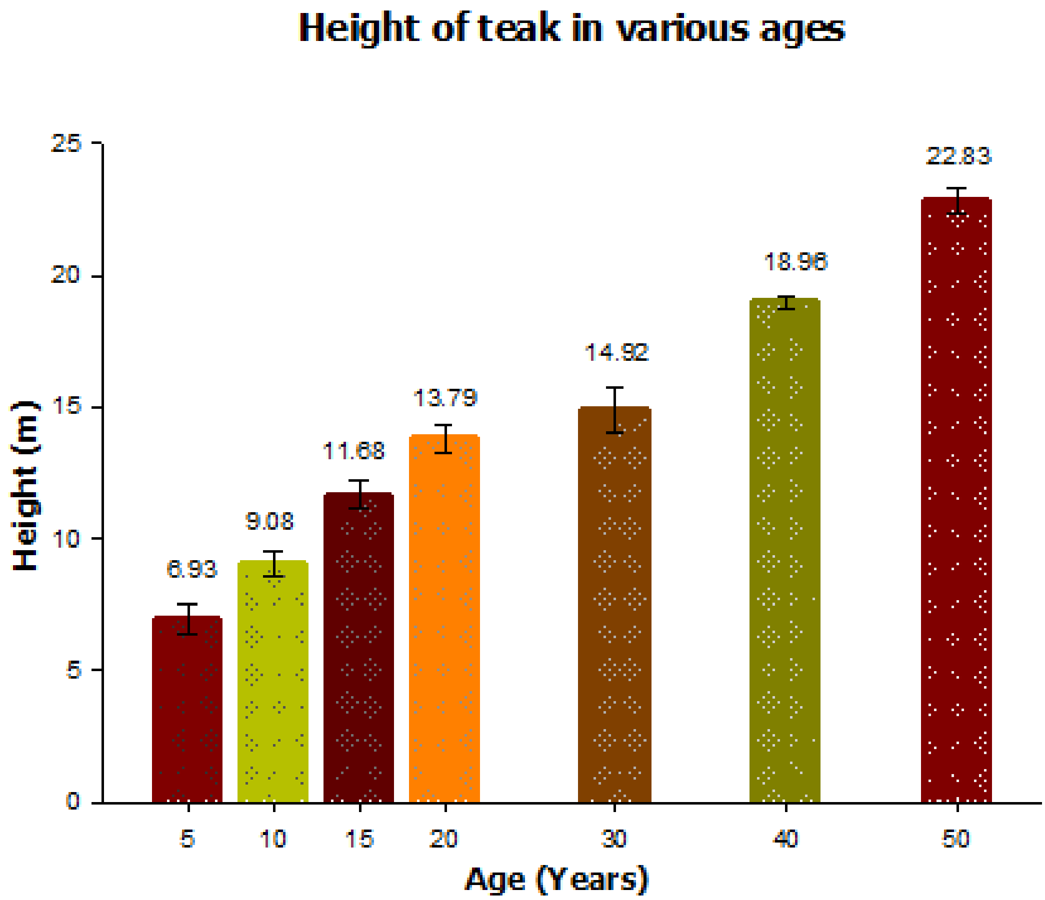


Figure 18-1 Teak height varied from 6.93 m at age of five years to 22.83 m at 50 years

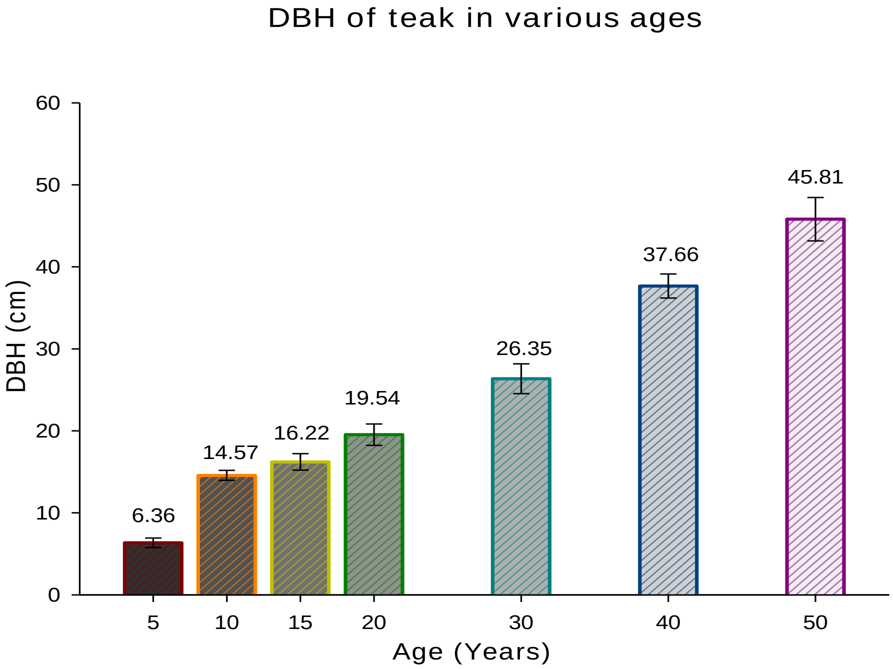


Figure 18-2 Diameter at breast height also increased with age from 6.36 cm to 45.01 cm from 5th year to 50th year respectively

Carbon content in various parts of teak of different age is given in Table 18-1. No significant difference was noted in the carbon content (37 to 44 percent) in different components. But the carbon sequestration by various components varied significantly with age and type (Table 18-2). Maximum carbon sequestered was by bole at the age of 50, nearly 322 kg per tree.

Table 18-1 Carbon content in various compartments of teak

Age (years)	**Carbon content (%)**			
	Bole wood	**Branch**	**Bark**	**Root**
5	45.19^{a} ±0.23	40.87^{a} ±0.29	37.65^{a} ±0.27	41.38^{a} ±0.52
10	45.43^{a} ±0.22	42.17^{b} ±0.17	39.96^{b} ±0.37	41.85^{a} ±0.30
15	45.99^{a} ±0.24	42.29^{b} ±0.24	40.69^{bc} ±0.38	42.70^{ab} ±0.28
20	46.03^{a} ±0.22	43.72^{c} ±0.22	40.93^{bc} ±0.33	42.81^{ab} ±0.30
30	47.73^{b} ±0.39	44.33^{c} ±0.33	41.25^{bc} ±0.50	43.53^{b} ±0.45
40	48.14^{b} ±0.35	44.38^{c} ±0.33	41.46^{bc} ±0.36	43.71^{b} ±0.45
50	48.85^{b} ±0.47	44.45^{c} ±0.35	41.78^{c} ±0.48	44.24^{b} ±0.50

Values in the table are Mean ± SE, n=12, significant at 0.05 level, (Values with same superscripts do not differ significantly and are homogenous within a column.

Table 18-2 Carbon sequestration in various compartments of teak

Age (years)	**Carbon sequestered (kg tree^{-1})**			
	Bole wood	**Branch**	**Bark**	**Root**
5	18.22a ±0.60	3.58a ±0.13	3.14a ±0.13	3.29a ±0.06
10	40.07a ±1.43	10.22ab ±1.10	5.63ab ±0.20	8.45ab ±0.33
15	48.58a ±3.05	14.40b ±0.80	6.53ab ±0.35	15.19ab ±0.99
20	63.18ab ±5.61	15.49b ±1.79	7.75ab ±0.63	19.76bc ±1.71
30	105.97b ±12.47	17.67b ±2.11	10.13b ±1.09	31.49c ±3.98

Age (years)	Carbon sequestered (kg tree^{-1})			
	Bole wood	Branch	Bark	Root
40	205.99c ±13.13	38.42c ±2.88	17.90c ±0.84	50.06d ±3.51
50	332.88d ±34.34	68.63d ±4.00	26.57d ±2.66	80.06e ±6.84

Values in the table are Mean ± SE, n=12, significant at 0.05 level, (Values with same superscripts do not differ significantly and are homogenous within a column)

The soil carbon content increased with age of the plantation and soil depth (Table 18-3). Maximum concentration was found in the upper 0 to 20 cm. Cumulative soil carbon was highest in 80-100 cm depth. Soil carbon increased with age due to annual litter fall and subsequent decomposition.

Table 18-3 Soil carbon stock in 50 year teak plantation

Soil depth (cm)	Bulk density (gcm^{-3})	Soil carbon (%)	Soil carbon (Mgha^{-1})	Cumulative soil carbon (Mgha^{-1})
0-20	$1.20^{a}\pm0.013$	$2.65^{a}\pm0.063$	$63.79^{a}\pm1.98$	$63.79^{a}\pm1.98$
20-40	$1.23^{ab}\pm0.011$	$2.11^{b}\pm0.053$	$51.81^{b}\pm1.47$	$115.60^{b}\pm3.26$
40-60	$1.23^{ab}\pm0.009$	$1.31^{c}\pm0.040$	$32.26^{c}\pm0.87$	$147.86^{c}\pm3.87$
60-80	$1.27^{b}\pm0.017$	$1.02^{d}\pm0.040$	$25.80^{d}\pm1.11$	$173.66^{d}\pm4.76$
80-100	$1.43^{c}\pm0.022$	$0.83^{e}\pm0.022$	$23.82^{e}\pm1.28$	$197.48^{e}\pm5.77$

Table 18-4 Thinning schedules of teak and trees removed per hectare

Sl. No.	Thinning Cycle	Age	Trees removed per ha.
1	1st thinning	5	1250
2	2nd thinning	10	448
3	3rd thinning	15	264
4	4th thinning	20	190
5	5th thinning	30	103
6	6th thinning	40	85
7	Final felling	50	160
		Grand total	**2,500**

(Ref: Growth and yield statistics of common Indian Timbers, FRI Dehra Dun, 1970 & Working Plan Nilambur North Forest Division, 2001)

Teak is planted initially at a spacing of 2 x 2 m. So, we have 2,500 plants / ha. But during the course of growth before final felling the plantation is thinned six times bringing the final number to 160/ ha (Table 18-4). The amount of carbon (t/ha) is given in Table 18-5. The total carbon varies from 35.29 to 81.30 t/ha during age from 5 to 50 years.

Table 18-5 Carbon sequestered at various thinning regimes of teak

Age	Trees removed	Carbon sequestered per hectare (tons ha^{-1})				
		Bole wood	Branch	Bark	Root	Total
5	1250	22.78	4.48	3.92	4.11	35.29
10	448	17.95	4.58	2.52	3.79	28.84
15	264	12.83	3.80	1.72	4.01	22.36
20	190	12.00	2.94	1.47	3.75	20.17
30	103	10.91	1.82	1.04	3.24	17.02
40	85	17.51	3.27	1.52	4.26	26.55
50	160	53.26	10.98	4.25	12.81	81.30

For the reference year 2014, an area of 4860 ha. of teak plantations were felled within age group of 5 to 50 years (Table 6). The total carbon sequestration potential can be arrived at 221.1 Gg.

Table 18-6 Carbon sequestration potential of teak plantations in Kerala for the year 2014

Age	Felling Area (ha)	Carbon sequestration in teak compartments (Gg*)				
		Bole wood	Branch	Bark	Root	Total
5	82.53	1.88	0.37	0.32	0.34	2.91
10	478.74	8.59	2.19	1.21	1.81	13.81
15	136.55	1.75	0.52	0.24	0.55	3.05
20	381.76	4.58	1.12	0.56	1.43	7.7
30	466.14	5.09	0.85	0.49	1.51	7.93
40	1529.83	26.79	5	2.33	6.51	40.62
50	1784.43	95.04	19.6	7.59	22.86	145.08
Total	**4860**	**143.72**	**29.64**	**12.73**	**35.01**	**221.1**

*Gg = 10^9 gram

Carbon Sequestration in Teak – Summary

Carbon sequestration in above-ground parts ranged from 25 kg/tree at 5 year to 428 kg/tree at 50th year. The respective contribution from belowground was 3.29 kg and 80kg/tree. Total carbon sequestration at final felling was found to be 508 kg/tree. Significant increase in carbon sequestration was noted after 20th year. Contribution of bole wood towards total carbon sequestration considering all ages together was 63% that by branch was 14%, by bark 7% and by root 16%. The initial years were not significantly different in carbon content irrespective of components but older trees were significantly different from younger trees in this respect (Montagmini & Porras, (1998).

Certified Emission Reduction (CER) potential for the reference year of teak plantations in Kerala, India is given in Table 18-7. It is assumed that an amount of INR 61.48 crores can be realised given 1 CER = 1 ton of CO_2= 12$, IPCC 2014.

Table 18-7 Certified Emission Reduction (CER) potential of teak plantations

Age	Carbon sequestered (Gg)	Equivalent No. of CERs	Price (INR)
5	2.91	10,678	0.81
10	13.81	50,616	3.84
15	3.05	11,194	0.85
20	7.70	28,234	2.14
30	7.93	29,090	2.21
40	40.62	1,48,922	11.29
50	145.08	5,31,900	40.34
Total	**221.10**	**8,10,634**	**61.48**

One ton of C = 3.67 tons of CO_2

1 CER = 1 ton of CO_2= 12$, IPCC 2014

Overall Summary

- Height, DBH and biomass increased in teak with age. Remarkable increase occurred after 30 years.
- At the final felling age of 50 years, a teak tree was found to attain 23 m height, 46 cm DBH and 1080 kg biomass.
- Carbon content in teak varied from 45-49 % in bole wood, 41-44% in branch and root and 38-42% in bark compartments during its growth from 5th to 50th year.
- Significant difference in carbon content was observed with age in the latter stages only.
- Carbon sequestration by a teak tree at final felling of 50th year was found to be 508 kg carbon per tree of which the above ground contributed 428 kg and the below ground 80 kg of carbon.
- Carbon sequestered in the soil up to 100 cm depth of a teak plantation was 166 tons per hectare.
- Among the different fractions of soil carbon, the passive carbon contributed double the active carbon; the intermediate fraction, slow carbon, was always less than the active carbon.
- Height, DBH and biomass increased in teak with age. Remarkable increase occurred after 30 years.
- At the final felling age of 50 years, a teak tree was found to attain 23 m height, 46 cm DBH and 1080 kg biomass.
- Carbon content in teak varied from 45-49 % in bole wood, 41-44% in branch and root and 38-42% in bark compartments during its growth from 5th to 50th year.
- Significant difference in carbon content was observed with age in the latter stages only.
- Carbon sequestered in the soil up to 100 cm depth of a teak plantation was 166 tons per hectare.
- Among the different fractions of soil carbon, the passive carbon contributed double the active carbon; the intermediate fraction, slow carbon, was always less than the active carbon.
- Teak plantations during 50 years of management could sequester 221.10 Gg of carbon equivalent to 8,10,634 certified emission reductions and can provide 61.48 crores of rupees at 2014 rates.

Converting CER into carbon credits

Payments for carbon sequestration present an opportunity for plantation and forest companies to gain a new revenue stream from their forests while reducing the impacts of climate change. Such payments also provide additional benefits:

- They gain a supplemental income that could help to make working forests profitable, preventing the need to sell or develop land.
- Sustainable forest management is encouraged.
- The public gains the many services that healthy forestlands provide, such as clean water, wildlife habitat and open space.

There is the potential for the entire world to benefit. At the same time, forest owners must be aware of the challenges that accompany forest carbon projects. Offset development can be complex and expensive. Given the high level of uncertainty regarding carbon regulation and fluctuating carbon prices, companies should consider not only the potential return but also the financial risk associated with forest carbon projects.

The opportunity to obtain carbon funding for activities that maintain or increase forest cover is exciting and real. The sector is growing rapidly from historically low transaction volumes as more carbon accounting methodologies are being approved and the number of high-quality projects is increasing.

Key eligibility requirements

1. Additionality-requires Forest projects to sequester more carbon than Business as usual scenario. The project must demonstrate that carbon sequestration would not happen without the development of the specific offset project.
2. Permanence- maintenance of Additionality for a specific accepted period.
3. Non-leakage- loss of sequestered carbon due to degradation, fire, and unsustainable practices.

General sequence of the project and issuance of credits.

1. Registration and approval of methodology
2. Monitoring
3. Verification (third party)
4. Validation (third party)
5. Approval or rejection by executive body
6. Credit issuance

Criteria for sustainable teak plantation management

Thanks to public concern about the environment, the issue of sustainability is now high on the agenda of many of the world's politicians. It is almost unimaginable that there could ever be a return to the old attitudes that focused primarily on sustainable timber production. Although we face a long and uncertain path to the ultimate achievement of sustainable management of the world's forests, public pressure has already moved forest policies a significant distance. If managed sustainably, forest ecosystems can provide multiple social, economic and environmental benefits for current and future generations and may contribute significantly to sustainable development. What are the three components of sustainable forestry.

Each of the elements- **economic prosperity, environmental protection, and social well-being-** is interdependent with the others, and each may be present to a greater or lesser degree in a particular situation.

The International Tropical Timber Organisation (ITTO) introduced the Criteria and Indicators concept and terminology in 1992. Since then several regional groupings of countries have worked together upon the process of generating and testing appropriate C&I to suit their own conditions (Sankar et al., 2000) The following are the major criteria.

CRITERION 1 Enabling Conditions for Sustainable Forest Management
CRITERION 2 Forest Resource Security
CRITERION 3 Forest Ecosystems Health and Condition
CRITERION 4 Flow of forest produce
CRITERION 5 Biological Diversity
CRITERION 6 Soil and Water
CRITERION 7 Economic, Social and Cultural Aspects

Given these criteria are maintained, the plantation can qualify for wood certification and also carbon credits.

Overall summary and recommendations

Teak is an important commercial timber species providing hardwood for various uses. This species is planted widely in Asia, Africa and Latin America. Being an efficient sequester of carbon, it can play an additional role in combating global warming through sustainable forestry projects. Further, the wood being long-lasting even after cutting through various products, teak is a good choice for receiving carbon credits. Thus, while raising plantations one has to look at all criteria for attaining ecological and social sustainability to address wood certification and carbon credits.

Acknowledgements

The Author is grateful to Dr. S. Sandeep, Soil Scientist, Kerala Forest Research Institute. Dr. P. K. Thulasidas, Consultant, ITTO Teak Mekong project and Mrs. M. P. Sreelakshmy, Teaknet Secretariat for support. I am thankful to Mrs. Divya Gopan for word processing the manuscript. I am be thankful to ITTO for providing me this opportunity.

References

Balagopalan, M., Rugmini, P. & Chacko, K. C. (2005). Soil conditions and growth of teak in successive rotations in Kerala State, India. In *Teak from Sustainable Forest Management* (eds., K.M. Bhat, K.K.N. Nair & K.V.Bhat), pp. 173-178. Kerala Forest Research Institute, Peechi, India.

FSI (2013). *State of Forest Report 2013. Forest Survey of India*, Dehra Dun, India.

Montagmini, F. & Porras, C. (1998) Evaluating the role of plantations as carbon sinks: An example of an integrative approach from the humid tropics, *Environ. and Mgt, 22*, 459-470.

Muralidharan, E. M., & Sharma, J. K. (2003) Quality timber products of teak from sustainable forest management. In *Proceedings of the International Conference on Quality Timber Products of Teak from Sustainable Forest Management,* pp. 173-178. 2nd-5th December 2003, Peechi, India.

UNFCCC. (2011). Report of the Global Environment Facility to the Conference of the Parties. Conference of the Parties Seventeenth session Durban, 28 November to 9 December 2011.

Sankar, S, Anil, P. C. & Amruth, M. (2000). *Criteria & Indicators for sustainable plantation management in India*. CIFOR

Chapter 19: Review of the Current Trade Trends of Tropical Timber and Timber Products

Tetra Yanuariadi and
Jean-Christophe Claudon

Abstract

Sustainably produced timber can store carbon in long-life timber products and substitute for emissions-intensive materials. The volume of timber produced sustainably in a tropical forest is generally extremely low, often as little as 1.5 m3 per hectare per year. Overall, this implies a continuing loss of competitiveness for tropical hardwoods compared to wood products produced in temperate forests. Changes in the global trading environment for tropical timbers are occurring at a rapid pace led in part by the rapidly declining availability and quality of large diameter tropical hardwood logs of primary wood species and easy availability of alternatives. Degraded forests have a reduced capacity to supply local, national and global markets with essential forest products. Yet demand for harvested timber and other products are increasing. If not addressed, the supply deficit of timber and other harvested forest products could reach several billion cubic meters per year. Demand for tropical primary and secondary wood products is a derived demand, driven by residential, non-residential and public construction activity and by consumer wealth and spending. Global housing and construction trends are therefore important indicators of tropical wood products demand. Housing and construction activities in United State, China, Japan and EU will influence the global building and construction trends. After reaching a its high point in 2014, tropical logs imports began to decline reaching its 30-year lowest in 2020. Tropical sawn wood imports have also been impacted as well by economic crises but still the total imports of tropical sawn wood were at the same level in 2020 as they were in 1990. Japan, the primary importer of tropical plywood responsible for 26% of global imports in 1990, has reduced its imports by half since 2008. This requires a longer-term view to enable tropical timber industry policy decisions to be effective.

Introduction

The International Tropical Timber Organization (ITTO) is an inter-governmental organization promoting the conservation and sustainable management, use and trade of tropical forest resources. Its members represent the bulk of the world's tropical forests and of the global tropical timber trade. Ensuring sustainable tropical timber trade requires optimizing the utilization and improving productivity of production forests, which will, in turn, benefit conservation and protected forests, in terms of reducing pressures and disturbances. Forests and timber and timber products are increasingly seen as important contributors to the Sustainable Development Goals, including SDG 13 ("climate action"). Among other things, sustainably produced timber can store carbon in long-life timber products and substitute for emissions-intensive materials.

The Asia Pacific region is an important region for efforts to sustain tropical forests and tropical timber and timber products trade. Indonesia, Malaysia, Myanmar, Philippines, Thailand and Vietnam are important producer countries in the region for tropical timber and timber products. However, forests and landscapes in the Asia-Pacific region are under increasing pressure from climate change, economic growth, infrastructure development, forest conversion, conflicts and other destructive activities. The economic viability of sustainable tropical forestry is often marginal at best, with returns from sustainable timber production and other marketable goods and services comparing poorly to those of alternate land uses. ITTO and its member countries have long recognized that natural tropical forests have great difficulty in attracting investments to help realize their potential to contribute to sustainable development.

The consumption patterns of forest products is changing rapidly in the region. The traditional use of wood as a source of domestic energy is declining rapidly as incomes rise and people move to cities, leading to the increased use of electricity and liquefied petroleum gas; on the other hand, the use of industrial roundwood (for sawn wood, paper and paperboard, and wood-based panels) is growing to cater to increased demand for housing, furniture and exports. Demand is also increasing for new types of forest products and ecosystemservices, such as amenity values, health-and-beauty products, and green space in urban landscapes. New wood-based products, such as biomaterials and biochemicals, are entering the market, and technological innovations are enabling the increased recycling of wood products (FAO, 2019).

Tropical Forest Situation

Deforestation and forest degradation continue to take place at alarming rates, which contributes significantly to the ongoing loss of biodiversity. Since 1990, it is estimated that 420 million hectares of forest have been lost through conversion to other land uses, although the rate of deforestation has decreased over the past three decades. Between 2015 and 2020, the rate of deforestation was estimated at 10 million hectares per year, down from 16 million hectares per year in the 1990s. The area of primary forest worldwide has decreased by over 80 million hectares since 1990 (Blaser et al., 2011; FAO, 2020).

In the current situation, the availability and quality of large-diameter tropical hardwood logs of primary wood species are declining. A contrast situation with the forest resources of the temperate zones which are generally either stable or increasing. Also, tropical forests tend to produce significantly lower volumes of saleable timber per hectare per year compared to temperate forests, less attractive for investment to increase productivity and for the establishment of plantations. According to ITTO (2010), the volume of timber produced sustainably in a tropical forest is generally extremely low, often as little as 1.5 m3 per hectare per year. Overall, this implies a continuing loss of competitiveness for tropical hardwoods compared to wood products produced in temperate forests.

These changes have transformed the Asia Pacific region's forests. According to FAO (2019), large areas of forest have been converted to other land uses, such as agriculture, infrastructure, mining, and oil-palm plantations. About 64 percent of the region's forests are now secondary, with varying levels of degradation. The area of planted forests doubled in the region between 1990 and 2015 to meet the growing demand for industrial roundwood. But not all forests are equal, and the shift from primary forests to secondary and planted forests entails sacrifices in the delivery of ecosystem services. Moreover, the region imports timber from other parts of the world to help meet demand, placing stress on forests outside the region

Market Developments of Tropical Timber and Timber Products

The raised profile of forests and timber products in the recent years owing to their role in mitigating climate change represents an opportunity for the forest sector to help build a bio-circular economy. Crucial for doing this is the development of green timber supply chains to ensure legality and sustainability, from the tree in the forest to the product in the market. Harnessing the benefits of legal and sustainable supply chains will require the strong commitment of, and coordinated and well-documented actions by, the many actors in supply and value chains (ITTO, 2020).

Tropical timber producer countries need to regularly assess the situation of competitiveness of their products in international markets to ensure continued maintenance of production and trade of sustainably managed tropical timber and timber products. Ensuring sustainable tropical timber trade requires optimizing the utilization and improving productivity of production forests, which will, in turn, benefit conservation and protected forests, in terms of reducing pressures and disturbances. A key requirement of sustainability is compliance with all relevant legal frameworks. The perception that illegal operations are widespread in tropical forests taints the image of the tropical timber sector in certain major import markets and while some markets have responded by introducing requirements for legality and sustainability to provide assurance for buyers and consumers many more are yet to initiate effective action in this regard. Over the past three decades the ITTO has been working with its members to strengthen forest governance and verify legality and sustainability, thereby improving the credentials of tropical forest products in global markets and has made noteworthy progress in this direction. Numerous policy measures are now being implemented to improve forest law enforcement and governance and counter the trade in illegally harvested timber (EUTR, US Lacey Act, Australian illegal logging prohibition bill 2012, and recently Japan clean wood act). Policy measures to improve forest low enforcement and governance also deals with forest certification, procurement policy and CITES species protection.

Trends: Tropical timber industry and trade

According to Held et al. (2019), demand for tropical primary and secondary wood products is a derived demand, driven by residential, non-residential and public construction activity and by consumer wealth and spending. Global housing and construction trends are therefore important indicators of tropical wood products demand. Housing and construction activities in United State, China, Japan and EU will influence the global building and construction trends. Changes in the global trading environment for tropical timbers are occurring at a rapid pace. Degraded forests have a reduced capacity to supply local, national and global markets with essential forest products. Yet demand for harvested timber and other products are increasing. If not addressed, the supply deficit of timber and other harvested forest products could reach several billion cubic meters per year.

According to Held et al. (2021), global resource use could double by 2050, representing an excellent trade opportunity for tropical timber producers. It forecasts that tropical industrial roundwood production will increase substantially by mid-century but says the sector needs a boost if it is to maximize its contribution to carbon-neutral production. A doubling of global resource use by 2050 would likely outstrip global sustainable supply and trigger negative impacts on biodiversity, climate, ecosystems and human wellbeing unless timely action is taken to mitigate these impacts. The world urgently needs to prioritize resource-use efficiency and adopt carbon-neutral production based on renewable and sustainably produced materials such as wood. According to the report, tropical timber could take a leading role in substitution because the increasing demand for goods in the construction sector and other sectors like plastics and textiles can partially be met by wood-based products.

The total production of tropical industrial roundwood is roughly 15% of the total production of industrial roundwood across the world. The Covid-19 pandemic has significantly reduced the production of tropical timber. For 2020, a drop in production of 10 million m^3 in the tropical countries representing a decline of 2-3% was forecast (Figure 19-1). At this point it is difficult to estimate the impact of the pandemic on production and domestic consumption of tropical logs.

The Asia-Pacific region produces two times more tropical industrial roundwood than the African and Latin American regions combined. Indonesia is the world's largest producer of tropical logs followed by India and Vietnam. PNG and the Solomon Islands are the largest exporters of tropical logs (combined they represent almost 50% of the world exports of tropical industrial roundwood) but are highly dependent on the Chinese demand. Their exports were strongly affected by the COVID19 crisis and declined by 23% and 17% respectively in 2020. Brazil became the third tropical logs exporter in 2020. The peak reached by the 'rest of the world' aggregate in 2014 is explained by the surge in exports by Myanmar prior to the enforcement of round log export ban. Myanmar's exports, however, plummeted to insignificant levels from 2015 when the ban was introduced.

In 1990, 30% of all industrial roundwood and 12% of sawn wood exported in the world was of tropical origin. Nowadays, this share is only around 9% and 6% respectively for tropical roundwood and sawn wood. Malaysia which exported 20 million m^3 of tropical logs in 1990 (71% of the world's total), exported just over a million m^3 in 2020. As for tropical plywood, its global import share was 75% in 1990, which has now dropped to only 25% of all plywood imports (Figure 19-2).

The Special Position of Teak

Among commercial tropical hardwoods, Teak (*Tectona grandis*) is recognized worldwide for its beauty, strength and stability. Over the past two decades, ITTO has been actively involved in research and development work in natural and planted teak forests and has supported teak projects with a focus on genetic resources conservation, seed production as well as sustainable management of natural and planted teak forests in Africa, Asia and Latin America. Three ITTO producer member countries, namely, Myanmar, India and Indonesia, are major teak players at the global level as they hold more than 95% of the world's natural and more than 75% of the world's planted teak forests. On consumer side, India, Thailand, and China are major importing countries in the world accounting for 74% of the world teak imports.

Myanmar is a teak heavyweight, playing a significant role in the global teak trade. It has the largest area of natural teak forests hosting almost 50 percent of 29 million ha globally, and is the number one producer of teak logs in the world. Its natural forests produce about a quarter of the globally reported teak log supply, including good-quality teak that sells at high prices. After India and Indonesia, the country also has the third-largest planted teak area in the world (about 390 000 ha), which is now reputed to be the source of more than 40 percent of the global teak trade (Kollert & Walotek, 2015).

The supply of high-quality teak logs originating from old-growth natural teak forests in Myanmar began to decline as a result of the log export ban that has been in force since 1 April 2014, reflecting both the declining harvestable area in natural teak forests and the deteriorating quality of naturally grown teak because of excessive harvesting of good quality trees over several decades in the past. This has led to increased interest and investment in establishing and managing teak plantations. It is more than likely that in the future, the world's supply of teak wood will depend mostly on the production from tropical teak plantations. Where good management practices are applied, plantation teak has improved both in productivity and in quality, and there could well be an increasing overlap in quality between natural and plantation-grown teak in future years (Kollert & Kleine, 2017).

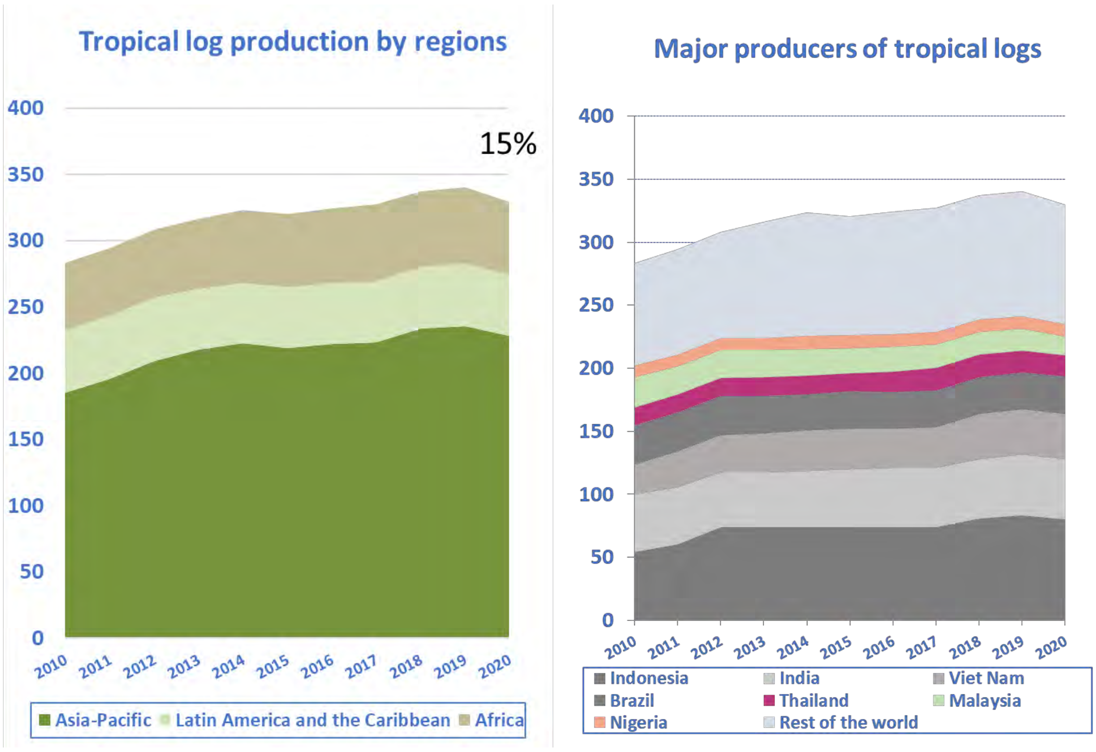


Figure 19-1 Production of tropical industrial roundwood (logs), 2010-2020, million m^3

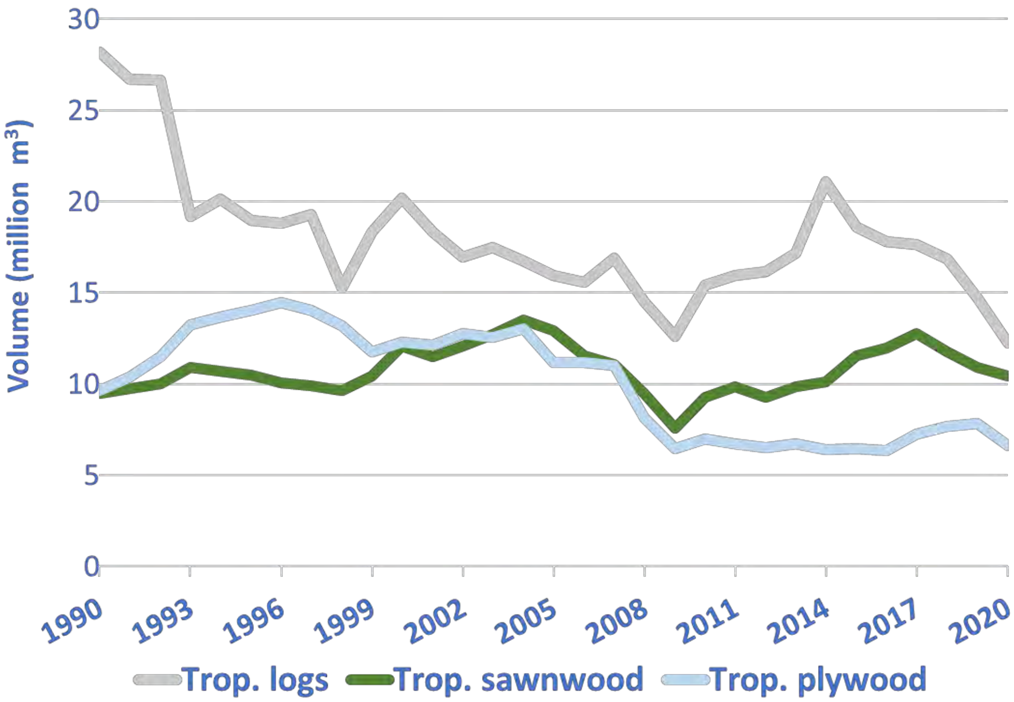


Figure 19-2 World imports of tropical primary wood products, 1990-2020

Tropical logs were mainly imported in Japan till the 1990s. In 1990 Japan imported 40% of all tropical logs but with its relative economic decline in the 1990s, Japanese imports started to dwindle. The Asian crisis of 1997-1998 depressed the tropical wood market briefly and the global financial crisis of 2008 affected it adversely for about four years. After reaching its high point in 2014, tropical logs imports began to decline and this decline has accelerated strongly from 2018 partly due to the economic slowdown in China. The COVID-19 crisis has amplified the economic slowdown in China and the volume of tropical logs traded in the world reached its 30-year lowest in 2020. Please see Figure 19-3 below for more information about major trade flows of tropical logs in 2020.

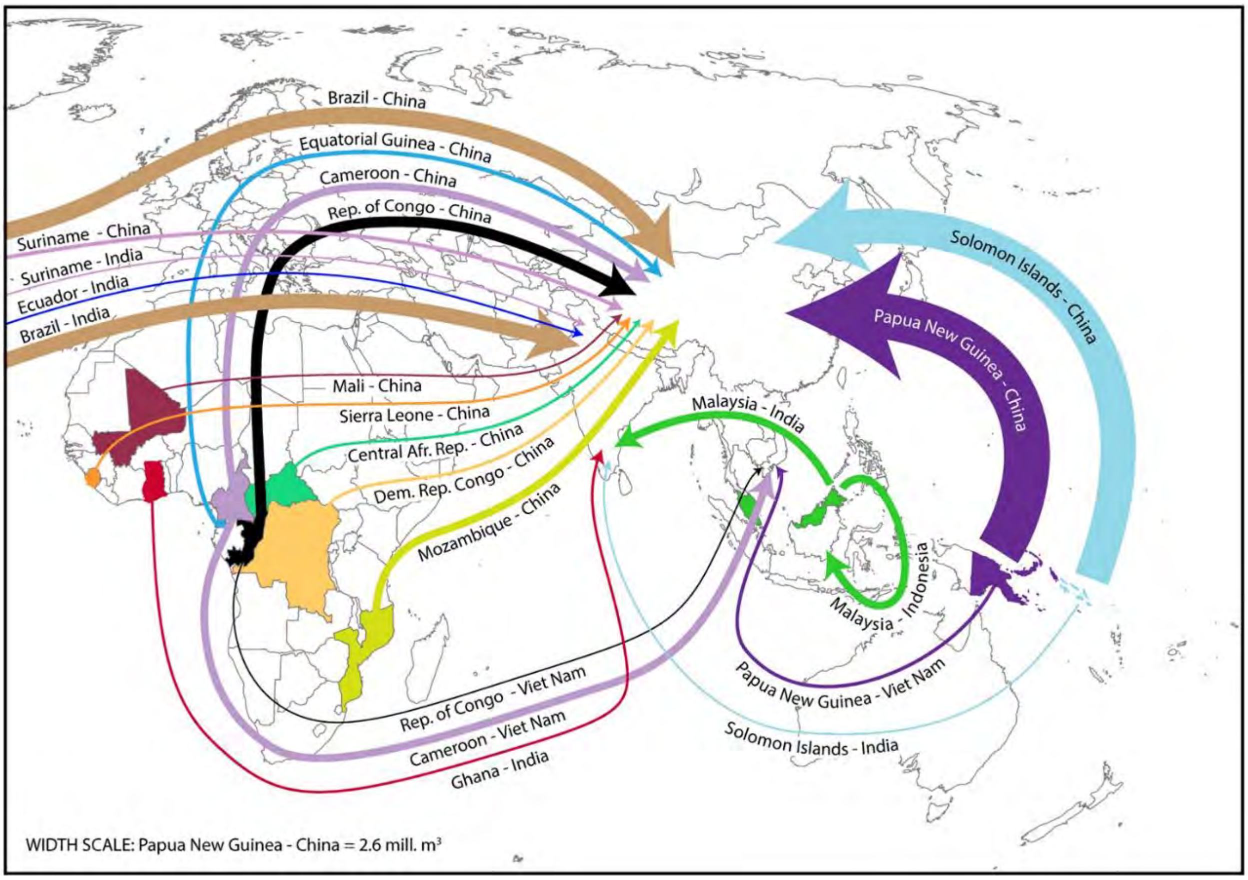


Figure 19-3 Major trade flows 2020: tropical logs

Tropical sawn wood imports have been impacted as well by economic crises. Nevertheless, unlike the roundwood imports, the total imports of tropical sawn wood were at the same level in 2020 as they were in 1990. China is the largest importer of tropical sawn wood at 63% of world's imports. After reaching a high point in 2017, its imports started to decline from 2018. In 2020, imports declined strongly during the first semester due to the pandemic but then rebounded during the second semester and finally China imported more tropical sawn wood in 2020 than in 2019. The EU is the second largest importer of tropical sawn wood and its imports declined by only 4% in 2020. Vietnam, the third largest importer of tropical sawn wood had its imports surge by 15% in 2020. Other major importers, however, experienced a double-digit percentage decline in 2020 and the 'rest of the world' aggregate was most affected registering a decline by a third.

Thus, despite declining world imports since 2017, tropical sawn wood has been more resilient to COVID-19 crisis than tropical logs (see Figure 19-4, Figure 19-5 and Figure 19-6), partly due to its higher value added in the supply chains.

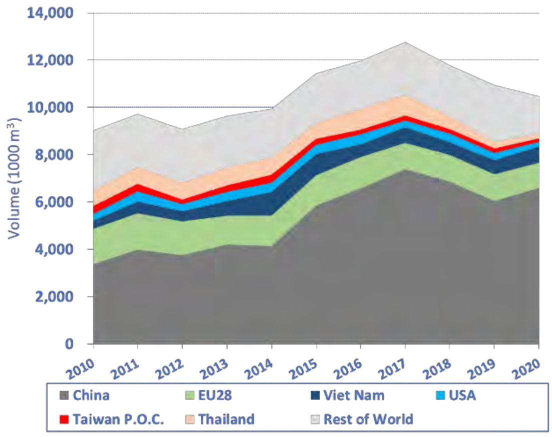


Figure 19-4 Major importers of tropical sawn wood, 2010-2020

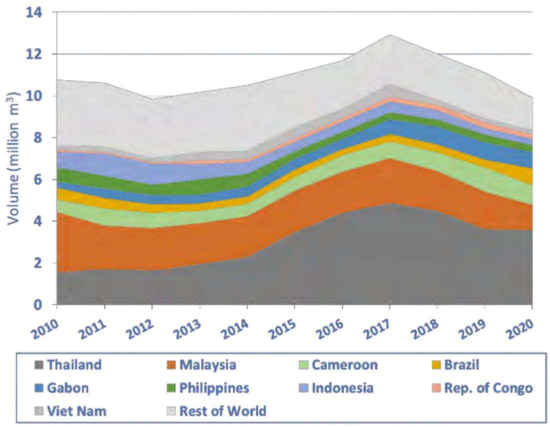


Figure 19-5 Major exporters of tropical sawn wood, 2010-2020

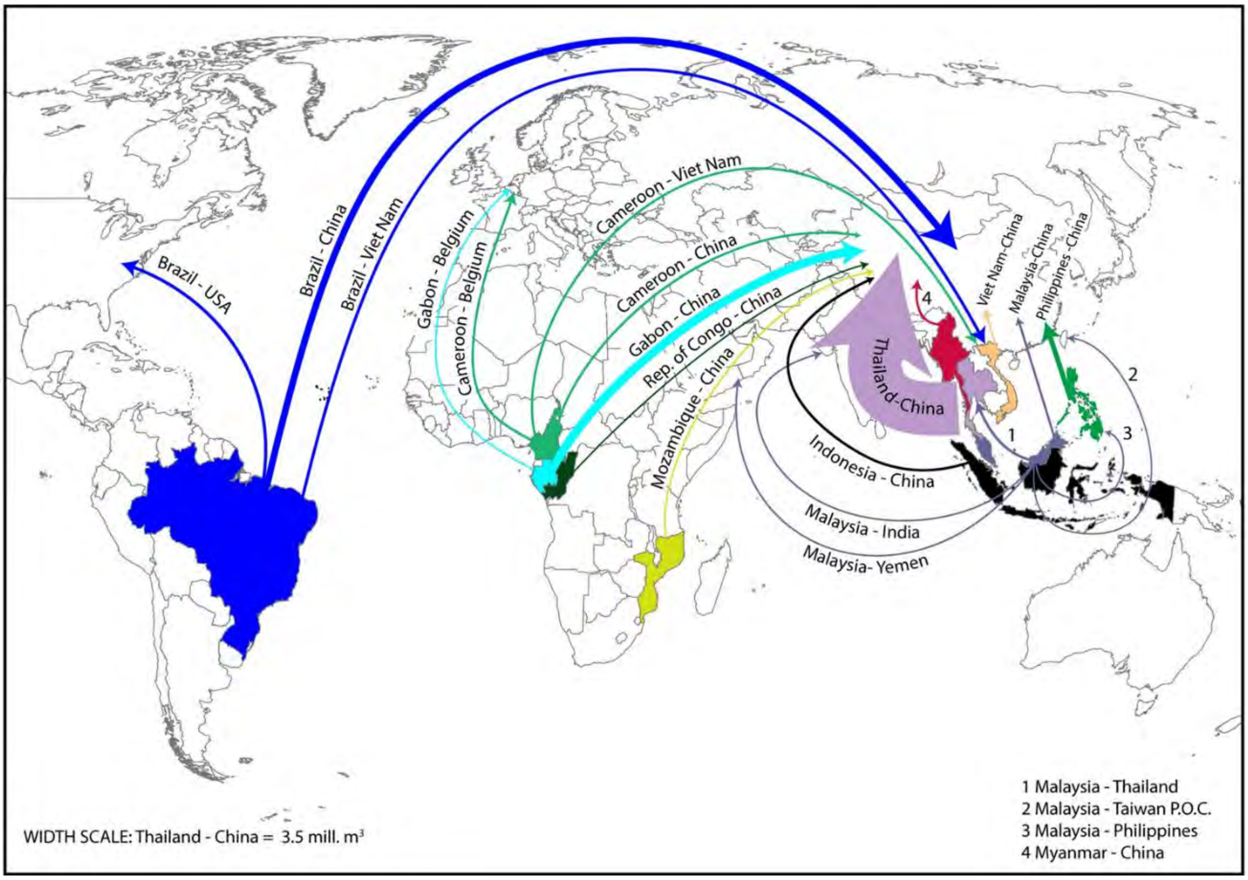


Figure 19-6 Major trade flows 2020: tropical sawn wood

Tropical plywood trade

Japan has been the primary importer of tropical plywood for longand the world imports was driven by Japanese imports. In 1990 they were responsible for 26% of global imports of tropical plywood. But there imports have dwindled sharply since the 2008 financial crisis and the global tropical plywood have never recovered since. Nevertheless, as global imports had already reached a low point, this product has been less affected than tropical logs and sawn wood by the current COVID-19 pandemic.

Indonesia is the biggest exporter of tropical plywood in the world. Its exports level accelerated in 2017 and 2018 before slowing down in 2019. It was strongly affected by the COVID-19 pandemic as its exports experienced a 22% decrease in 2020. Vietnam became the second biggest exporter of tropical plywood in the world overtaking Malaysia for the first time. Despite the COVID-19 crisis, its exports surged by 32% in 2020. Its major markets are the USA and the Republic of Korea. Malaysia has seen its exports of tropical plywood reducing drastically over the years having come down by a third over the past decade. The overall decline has been in response to chronic supply shortages of raw material input, the peeler logs, to the plywood mills and rising export prices, even as demand and prices remained depressed in its major market of Japan. At its peak in 2006, Malaysian tropical plywood exports were roughly around 5.1 million m^3 while exports recorded in 2020 were just around 1.3 million m^3. Indonesia, Vietnam, and Malaysia together accounted for 77% of the global exports of tropical plywood (see Figure 19-7, Figure 19-8 and Figure 19-9). About 90% of tropical plywood is produced in China and Southeast Asia and then exported mainly to the US, Japan, the Republic of Korea, and the EU. Demand in the US has been accelerating. Japan, despite a stagnant and declining demand, still remains a major consumer of tropical plywood.

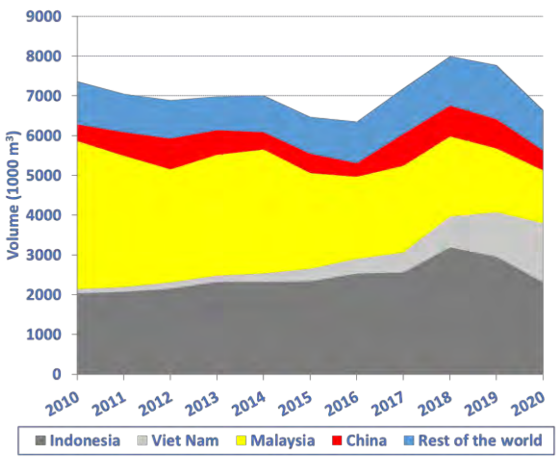


Figure 19-7 Major exporters of tropical plywood, 2010-2020

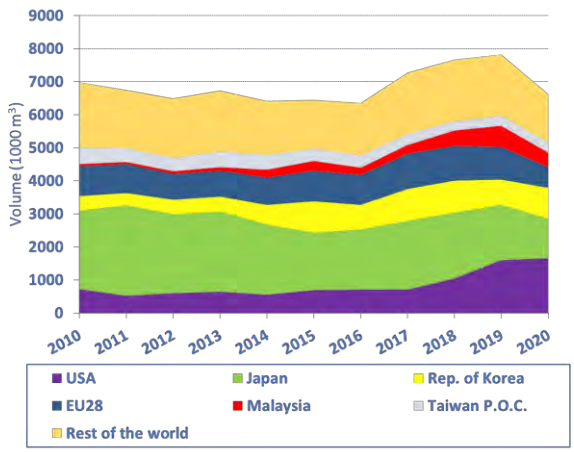


Figure 19-8 Major importers of tropical plywood, 2010-202

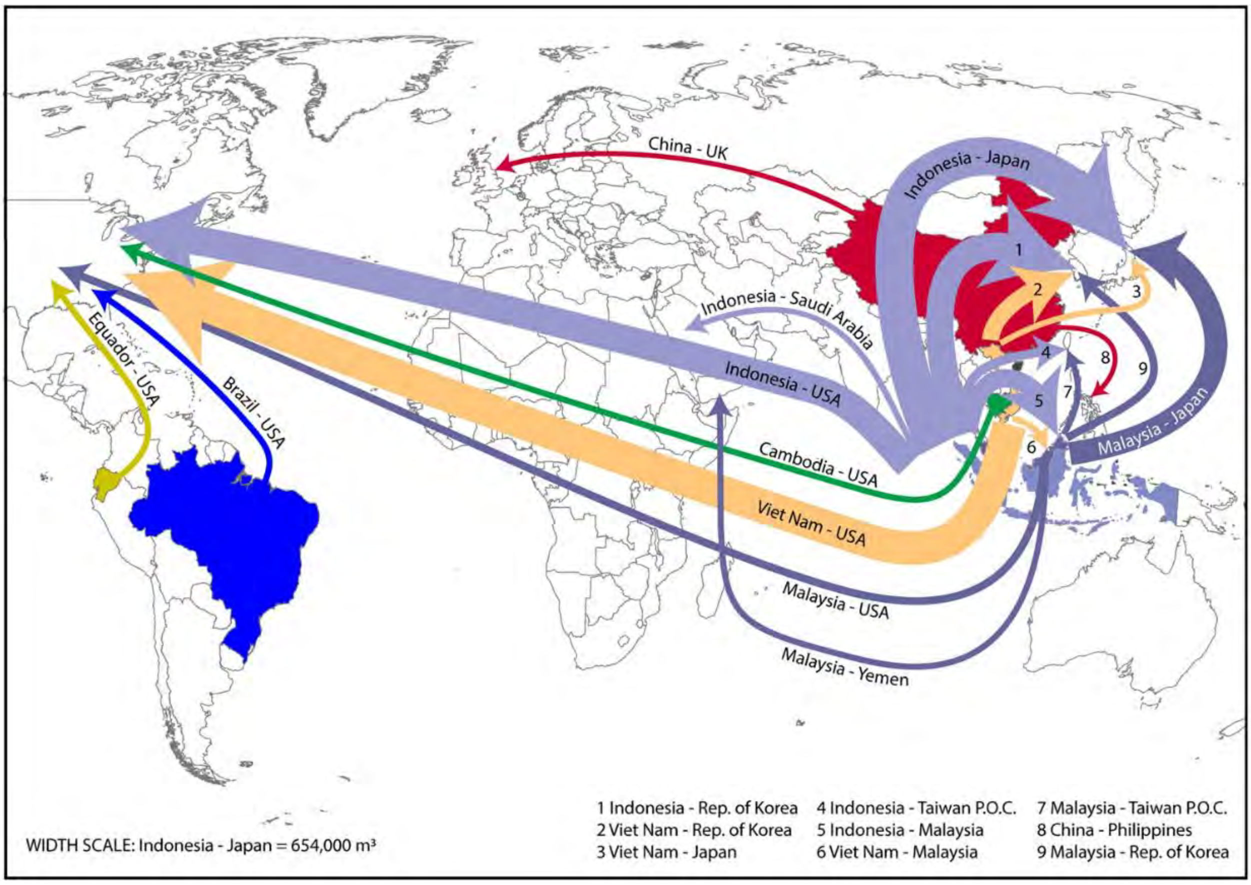


Figure 19-9 Major trade flows 2020: tropical plywood

Trade in Wooden Furniture

Vietnam is the biggest tropical exporter of furniture in the world at 57% of all tropical exports of furniture and its exports have almost tripled over the last 10 years. It exported over $10 billion of furniture in 2020 and its exports increased by an additional 15% between 2019 and 2020 despite the COVID-19 crisis as it has been advantaged by the China-USA trade dispute. For the first time ever, Vietnamese exports of furniture overtook the Chinese exports of furniture to the US with the Chinese exports declining by a third even as exports of furniture from Vietnam boomed by 27%. Vietnamese exports of furniture to the US have increased by the factor of 3 in just ten years. There has also been a trend towards outward investment by processors operating in China to Southeast Asia, particularly Vietnam, to avoid US tariffs and lower their production costs. Overall, the COVID-19 pandemic brought lesser impacts on the tropical furniture exports than on the primary wood products (see Figure 19-10 and Figure 19-11).

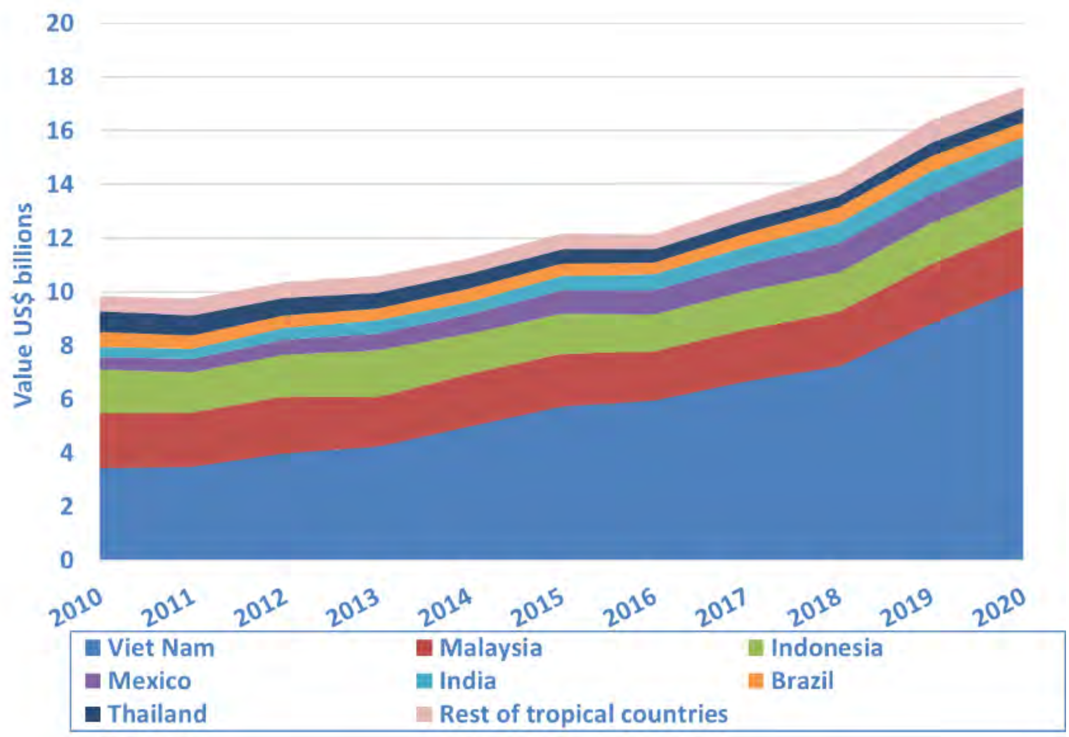


Figure 19-10 Major tropical exporters of furniture, 2010-2020

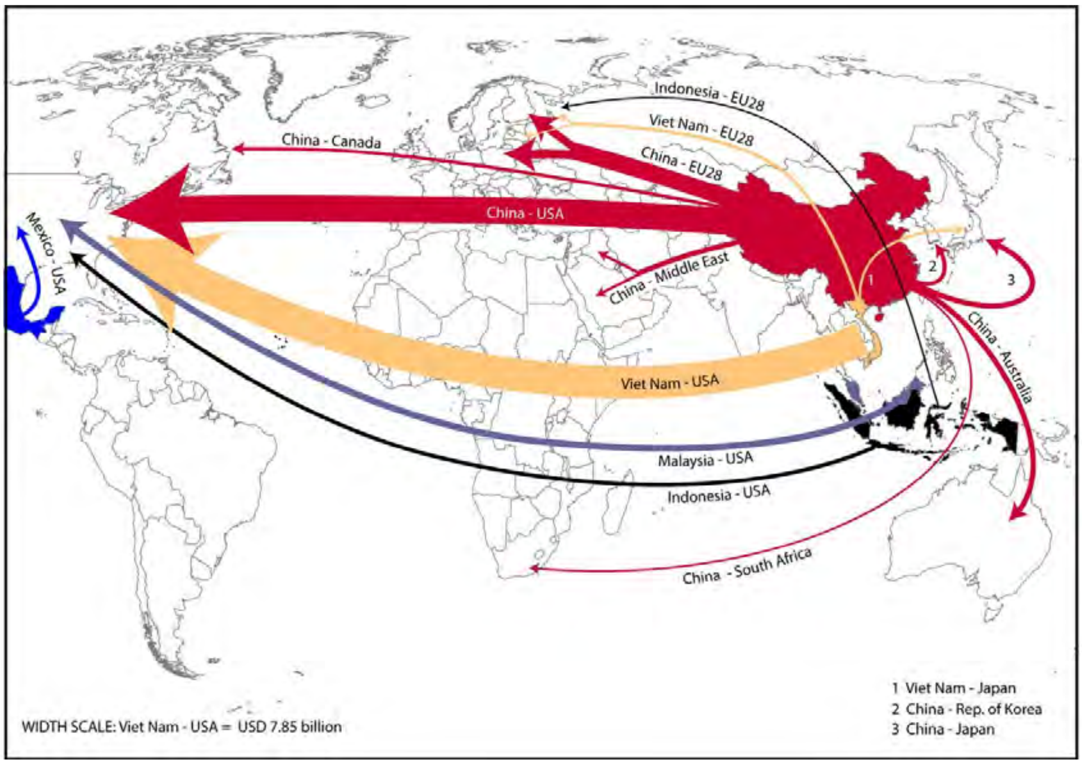


Figure 19-11 Major trade flows 2020: wooden furniture from China and ITTO producer countries

Conclusion

The raised profile of forests and timber products in the recent years owing to their role in mitigating climate change represents an opportunity for the forest sector to help build a bio-circular economy. Harnessing the benefits of legal and sustainable supply chains will require the strong commitment of, and coordinated and well-documented actions by, the many actors in supply and value chains. Tropical timber producer countries need to regularly assess the situation of competitiveness of their products in international markets to ensure continued maintenance of production and trade of sustainably managed tropical timber and timber products.

Important issues that influence market developments of tropical timber are economic trends, building and construction indicators and market policy trends. Global economic growth is a major indicator of demand for tropical wood products because of its impacts on housing, construction activity and consumer wealth and spending, all of which have flow-on effects on demand for wood-based products. The COVID-19 crisis has affected tropical timber and timber products trade and amplified the economic slowdown in its both producer and consumer countries.

The Asia Pacific region is an important region for efforts to sustain tropical forests and tropical timber and timber products trade. The consumption patterns of forest products is changing rapidly in the region. The Asia-Pacific region produces two times more tropical industrial roundwood than the African and Latin American regions combined. Indonesia is the world's largest producer of tropical logs followed by India and Vietnam.

Tropical logs imports began started to decline and this decline has accelerated strongly from 2018 partly due to the economic slowdown in China. The COVID-19 crisis has amplified the economic slowdown in China and the volume of tropical logs traded in the world reached its 30-year lowest in 2020. Tropical sawn wood imports have been impacted as well by economic crises. Nevertheless, unlike the tropical logs roundwood imports, the total imports of tropical sawn wood were at the same level in 2020 as they were in 1990. Japan has been the primary importer of Tropical plywood and the world imports was driven by Japanese imports. In 1990 they were responsible for 26% of global imports of tropical plywood. Japanese imports have been divided by 2 since 2008 and the global tropical plywood have never recovered since. Nevertheless, as global imports had already reached a low point, this product has been less affected than tropical logs and sawn wood by the current COVID-19 pandemic.

Global resource use could double by 2050, representing an opportunity for tropical timber producers. However, this doubling resource use would likely outstrip global sustainable supply and trigger negative impacts on biodiversity, climate, ecosystems and human wellbeing. Therefore, the world urgently needs to prioritize resource-use efficiency and adopt carbon-neutral production. Tropical timber could take a leading role in substitution because the increasing demand for goods in the construction sector and other sectors like plastics and textiles can partially be met by wood-based products.

References

Blaser, J., Sarre, A., Poore, D. & Johnson, S. (2011). *Status of Tropical Forest Management 2011*. ITTO Technical Series No 38. International Tropical Timber Organization, Yokohama, Japan.

FAO & UNEP. (2020). *The State of the World's Forests 2020. Forests, biodiversity and people*. Rome, Italy. https://doi.org/10.4060/ca8642en

FAO (Food and Agriculture Organization of the United Nations). (2019). *Forest* *futures – Sustainable pathways for forests, landscapes and people in the Asia-Pacific region. Asia-Pacific Forest Sector Outlook Study III*. Bangkok, Thailand. http://www.fao.org/3/ca4627en/CA4627EN.pdf

FAO (Food and Agriculture Organization of the United Nations). (2020). *Global Forest Resources Assessment 2020*. http://www.fao.org/forest-resources-assessment/2020/en/

Held, C., Meier-Landsberg, E. & Alonso, V. (2021). *Tropical Timber 2050. An analysis of the future supply of and demand for tropical timber and its contributions to a sustainable economy*. ITTO Technical Series No. 49. International Tropical Timber Organization (ITTO), Yokohama, Japan.

ITTO (The International Tropical Timber Organization). (2010). *Leveling the playing field*. https://www.itto.int/technical_report/
ITTO (The International Tropical Timber Organization). (2019). *Biennial review and assessment of the world timber situation 2017-2018.* https://www.itto.int/direct/topics/topics_pdf_download/topics_id=6162&no=1

ITTO (The International Tropical Timber Organization). (2020). *Report of the International Forum: Together Towards Global Green Supply Chains*. International Tropical Timber Organization (ITTO), Yokohama, Japan.

Kollert, W. & Kleine, M. (2017). *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources*. IUFRO World Series Volume 36, Vienna.

Kollert, W. & Walotek, P. (2015). Global teak trade in the aftermath of Myanmar's log export ban. *Planted Forests and Trees Working Paper,* 49(49), 20.

SECTION V
RESEARCH IN TEAK GENETICS

Chapter 20: Conservation Approaches of Teak Genetic Resources in Thailand

Suwan Tangmitcharoen

Abstract

Teak is among the most important of the economically valuable tree species in Thailand which has been prioritized for conservation and management as a genetic resource**.**

The Royal Forest Department (RFD) and the Department of National Parks, Wildlife and Plant Conservation (DNP) are the two key government departments in charge of conservation of genetic resources in Thailand deals primarily with *ex-situ* and *in-situ* conservation, respectively. Natural teak is well preserved in protected areas including national parks, wildlife sanctuaries, non-hunting areas and forest parks covering an area of 2.59 million ha (constituting 59% of natural teak forests) while 41% of natural teak forests fall outside protected areas, mainly in national reserved forest covering an area of 595,000 million ha (3.7 millon rai). In 2006 the DNP reported new discovery of teak at high elevations of up to 1,230 m which was reported earlier about 100-900 elevation. The species naturally occurs with dense population namely the "Nawawintara Rachinee Teak covering area of 9,600 ha (60,000 rai).

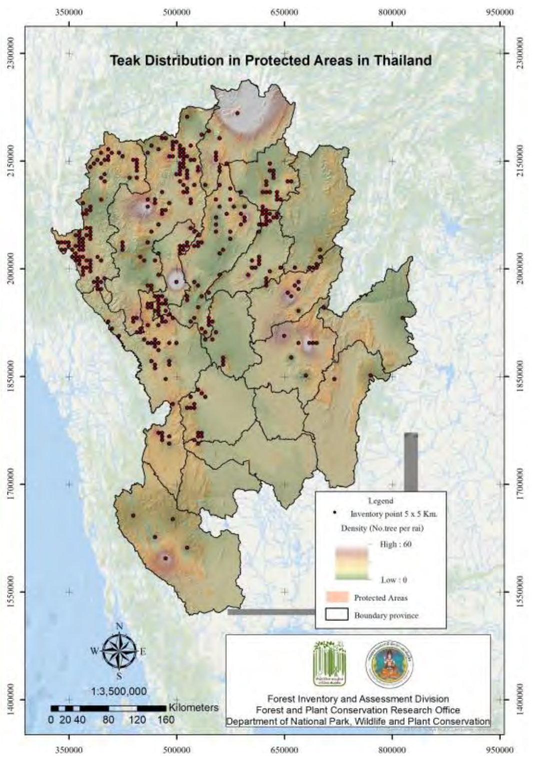
Ex-situ gene conservation was launched in 1965 under the Teak Improvement Program in cooperation with Danish International Development Agency (DANIDA). Majority of *ex-situ* conservation in the form of clone banks established to preserve the genetic traits of plus trees from across the country in safe places and to facilitate management of genetic materials for teak improvement activities. Total of 509 clones were established during 1965-2009 for clone bank purpose. As for clonal test, total of 636 clones have been tested during 1988 – 2021 in the North, Northeast, Central and South. For provenance trial, it started when the teak improvement program was launch in 1965. Domestic provenance trials were conducted during 1966-1969. Half-sib and full-sib progeny trials were planted during 2008-2011 at four regions of Thailand. As for full-sib, the progenies of the year 2008 and 2010 were hand-controlled-pollinated during the year 2005 and 2008, respectively. Teak seed orchards are the largest tree improvement plots in Thailand covering an area of 978 ha. The majority of seed orchards in Thailand are clonal seed orchards (CSOs) composed of vegetative copies of selected genotypes. This article also mention recommendation from the World Teak Conference 2013 held in Bangkok including lessons learned and recommendation from practices in Thailand.

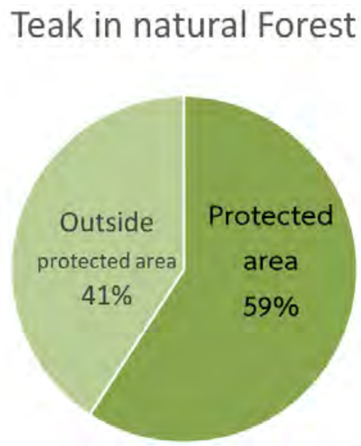
Introduction

The Royal Forest Department (RFD) and the Department of National Parks, Wildlife and Plant Conservation (DNP) are the two key government departments in charge of conservation of genetic resources in Thailand of which the former focuses on *ex-situ* conservation and management in terms of economic use while the latter deals primarily with *in-situ* conservation. Teak is among the most important of the economically valuable tree species which has been prioritized for conservation and management as a genetic resource (Changtragoon et al, 2012; Tangmitcharoen, 2009a; Tangmitcharoen, 2009b).

Teak has large geographically natural distribution area covering parts of India, Myanmar, Thailand and Laos (Kaosa-ard, 1981). It also grows in Indonesia (Java), where presumably it was introduced between in the beginning of the fourteenth and sixteenth centuries (Verhaegen et al., 2005). Recently, DNP (2021) reported natural distribution of teak forest covering an area of 1.457 million ha (9.1 million rai) in protected areas and outside protected area which is less than that reported earlier (Sumantakul & Sangkul, 1998; Kijkar, 2003). Natural teak is well preserved in Protected Areas including national parks, wildlife sanctuaries, non-hunting areas and forest parks covering an area of 2.59 million ha (constituting 59% of natural teak forests) while 41% of natural teak forests fall outside protected areas, mainly in national reserved forest covering an area of 595,000 million ha (3.7 million rai) (Figure 20-1).

The species occurs naturally in a wide range of environmental conditions from dry places with only 500 mm annual rain up to areas with 5,000 mm but optimum conditions are in areas having between 1,200 and 2,500 mm annual rainfall (Kaosa-ard 1981). Kijkar (2003) reported that teak in Thailand occurred naturally in the north, stretching from 14^0 to $20^0$31'N latitudes and between 97^0 30 -104^0-30'E longitudes, from about 100-900 m elevation. In 2006 the DNP) reported teak at high elevations of up to 1,230 m. This new discovery of teak at high elevation synchronizes with teak distribution in India which report that it grows well from sea level to an elevation of 1,200 meters (Katwal, 2003). The "Nawawintara Rachinee teak forest" has been specially set up under teak genetic conservation projects in the Pai basin forests under a Royal Initiative. The species naturally occurs with dense population mainly in LumNamPai wildlife sanctuary and West Mae-Pai national reserved forests in Maehongsong province covering area of 9,600 ha (60,000 rai) (OCRP, 2017) (Photo 20-1). Nawawintara Rachinee teak forest is well known for its abundance of teak in the country.





	Area		%
	rai	ha	
Protected area	5,390,625	862,500	59
Outside protected area	3,718,750	595,000	41
Total	9,109,375	1,457,500	100

Figure 20-1 Teak distribution in natural forest in Thailand in protected area and outside (Source: DNP, 2021)


Photo 20-1 Nawawintara Rachinee teak forest in MaeHonSong province spread over 9,600 ha (Credits: Mr.Treepop Tipayasak & Dr.Saroj Wattanasuksakul)

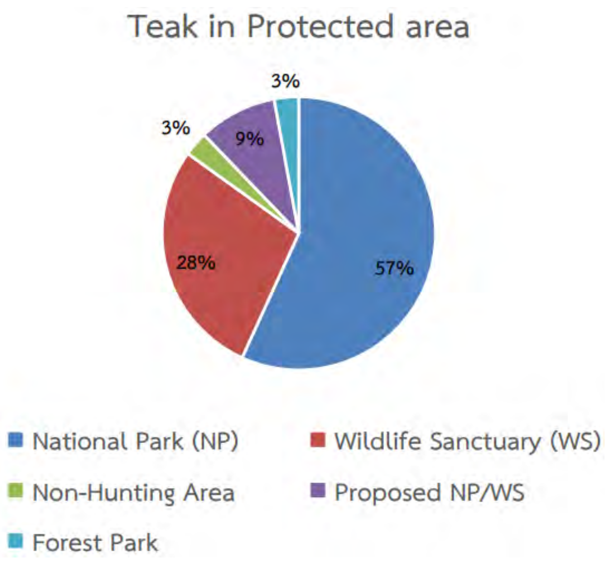
In-situ Gene Conservation Actions of Teak

Thailand has set up a target to have 25% of the country's total land area as protected áreas for *in-situ* conservation of everything that exists on these lands. At present, protected areas declared by Royal Decrees account for about 22.6% (11.68 million ha) of the country's total land area (DNP, 2020). These protected areas are generally well preserved because of stringent laws and regulations in force over these lands.

Protected Areas with teak as an important part of the natural ecosystem covers an area of 862,500 ha* and are located mainly in the northern parts of Thailand. Of this about 490,000 há falls under different national parks, 242,500 há under wildlife sanctuaries, 25500 há under non-hunting áreas, 25000 há under forest parks. Another 80000 há are proposed to be included in the national parks and wildlife sanctuaries expected to be notified in the near future (DNP, 2021) (Photo 20-2).

Apart from these, there is a biosphere reserve announced by UNESCO, namely Hauy Tak Teak Biosphere Reserve (HTBR) located at 18°20' to 19°05'N; 99°45' to 100°05'E which is partly in the proposed Tampham Pha Thai National Park. The park, located in Lampang Province, is a unique protected area among the four biosphere reserves in Thailand the core area of which is dominated by purê stands of teak interspersed with trees of mixed deciduous forests. It is now recognized as gene banks of teak in Thailand. Six distinct types of natural forests exist in the area, namely, Pine Forests, Hill Evergreen Forests, Dry Evergreen Forests, Moist Evergreen Forests, and Mixed Deciduous Forests. Part of Tampham Pha Thai National Park extending over 29,440 há in Ngao district of Lampang province has been divided into core zone (2680 há), buffer zone (20,060 ha) and transition zone (6,700 ha). Hauk Tak forest is recognized for its potential as a model site for studying sustainable forest management and as a training ground for forestry managers and researchers (UNESCO, 2019).

Note: * estimation of teak areas based on survey point mutiply by 25 km^2 (5x5 km).



	Area		%
	rai	ha	
National Park (NP)	3,062,500	490,000	57
Wildlife Sanctuary (WS)	1,515,625	242,500	28
Non-Hunting Area	156,250	25,000	3
Proposed NP/WS	500,000	80,000	9
Forest Park	156,250	25,000	3
Total	5,390,625	862,500	100

Photo 20-2 Teak distribution across different types of protected areas in Thailand (Source: DNP, 2021)

Photo 20-3 Hauy Tak Teak Biosphere Reserve in Lampang Province

***Ex-situ* Gene Conservation Actions of Teak**

Ex-situ gene conservation of forest genentic resources (FGR) in Thailand is mostly carried out in the form of specific area conservation, field collection of seeds, and the establishment of field gene banks that serve both as storage of diverse plant species and as laboratories for research and development. These sites are located across the country in the forms of (i) Plantation stands in the of gene banks,

gene conservation plots, botanical gardens, arboretums, etc. and (ii) Tree improvement

plots such as clone banks, progeny tests, provenance trials, clonal tests and seed orchards. *Ex-situ* gene conservation, as a formal government effort, was launched in 1965 under the Teak Improvement Program in cooperation with DANIDA.

Plantation stands

Majority of *ex-situ* conservation in the form of clone banks established to preserve the genetic traits of plus trees from across the country in safe places and to facilitate management of genetic materials for teak improvement activities. Total of 509 clones were established during 1965-2009 for clone bank purpose in northern, western, and northeast in Silvicultural Research Stations (SRS) at Phayao, Lampang, Phitsanulok, Kanchnaburi, and Khonkaen, respectively.

Photo 20-4 Clone bank at Ngao SRS with collection of 396 clones over 5.76 ha (Left) and Maegar SRS with collection of 113 clones over 0.5 ha (Right)
(Credits: Chumnun Piananurak & Somporn Khumchompoo)

Clonal test

Clonal test is a field planting of many vegetatively propagated plus trees serving as germplasm collection in the form of tree improvement plot. The test aims to evaluate genotypic value of the selected clones for further development by planting plus trees from different sources under the same environment. A total of 636 clones have been tested during 1988 – 2021 at four regions of Thailand (North, Northeast, Central and South) (Table 20-1, Photo 20-5) of which the most recent set has been established in 2021 under the ITTO Mekong Teak Project.

Table 20-1 Teak clonal test planted during 1988-2021 at four regions of Thailand

Set	Station name	Province	Region	Spacing (m)	Planted year	Number of tested clones
1	Ngao SRS	Lampang	North	3x3	1988	*
2	Ngao SRS	Lampang	North	4x4	2006	100
	ThongPhaPoom SRS	Kanchanaburi	Central		2000	100
	KhamPhangPhet SRS	KhamPhangPhet	Central		2001	100
	Songkhla SRS	SongKhla	South		2003	100
3	ThungKwian	Lampang	North	4x4	2021	100
	ThongPhaPoom SRS	Kanchanaburi	Central		2021	
	Donglan SRS	Khonkaen	Northeast		2021	
	Total					500

Note: * clones of this set were used for the second set.

Photo 20-5 Clonal test plots at Ngao SRS in the North (left) and Thongphapoom SRS in Central Thailand (right)

Provenance trials

Provenance trials is a special type of plantation experiment that examines how trees are adapted to different environmental conditions through genetic adaptation or phenotypic plasticity. Provenance means "origin" and refers to a population of trees that come from a particular location. It is designed to identify regions and individual provenances that have the greatest productivity. To establish a provenance trial series, seeds are collected throughout an area of interest. This can be the entire species range or an administrative region. Then, the seedlings from all collection locations are planted together in a systematic experimental design on one, or preferably multiple, sites. In Thailand, the provenance trials started when the teak improvement program was launch in 1965. Domestic provenance trials were conducted during 1966-1969 (Hedegart, 1974; Kanchanaburangura, 1976) and international provenances trials during 1972-1974. (RFD, 2013).

For domestic trials, 32 different seed sources were collected for planting at six sites in Lampang, Phayao, Uttraradit, Chiangrai, Nakhonratchsima, and Chantaburi provinces in north, northeast and eastern regions of Thailand. Of these the plots at Chiangrai and Nakhonratchasima have been damaged by forest fires. Chiangrai provenance (S34) and Lampang provenance (S88) have shown the best performance in terms of height at 8 years age at Lampang and Uttraradit plots, respectively.

For international trials, Kjaer (2003) reported that differences between provenance could be observed, but the variation between Thai provinces was not large compared to what has been observed in other country tests. The test of provenances from India, Laos, Indonesia, Africa, Thailand were established in 1974 at Lampang with 3 provenances from India, 4 from Thailand, 1 from Indonesia, and at Khonkean with 9 provenances from India, 5 Indonesia, 6 Thailand, 4 Africa, and 1 landrace. Evaluation of the international provenance test has been conducted at 9, 14, 24 years age. General results of Lampang plot showed that growth and stem form of Thai and Indonesia provenances showed better performance compared to those from India. At the Khonkean plot, however, trees from Thai provenances and Laos provenances showed superior stem form but in terms of growth performance, trees from Indonesia and India (semi-moist) were better than those from Thailand, Laos, and India (moist) (RFD, 2013).

Progeny test

Progeny test is another form of germplasm collection by accumulating germplasm from different parents to compare the off springs. Half-sib and full-sib progeny trials were planted during 2008-2011 covering an area of 27.3 ha (171 rai) at four regions of Thailand (Table 20-2). The first promising half-sib progeny trials were planted in 2011 with 295 families from 180 plus trees. Plus trees were collected from Phayao, Lampang, Khonkaen, from seed orchard of Maegar SRS, breeding orchard Ngao SRS, and seed orchard in Donglan, respectively. As for full-sib, the progenies of the year 2008 and 2010 were hand-controlled-pollinated during the year 2005 and 2008, respectively.

Table 20-2 Progeny test conducted during 2008-2011

Type of progeny	Planting year		No of family	Station name	Province	Area	
	A.C.	B.E.				ha	rai
Full-sib	2551	2008	50	Donglan SRS	Khonkaen	2.88	18
					Phitsanulok	2.88	18
				Phitsanulok SRS	Kanchanaburi	2.88	18
				Thongphapoom			
Full-sib	2553	2010	12	Donglan SRS	Khonkaen	1.92	12
				Phitsanulok SRS	Phitsanulok	1.92	12
				Central SR Center	Kanchanaburi	1.92	12
Half-sib	2554	2011	295	Inthakin SRS	Chiangmai	4.3	27
				Donglan SRS	Khonkaen	4.3	27
				Bantakhun	Surathani	4.3	27
Total						27.3	171

Seed Orchard

Seed orchard is an intensive plantation of trees selected specifically for the mass production of genetically improved seeds and, sometimes, for combining with progeny testing, too. It is a link between breeding programs and plantation establishment. They are designed and managed to produce seeds of superior genetic quality compared to those obtained from seed production areas, seed stands, or unimproved stands.

For the purpose of *ex-situ* gene conservation, seed orchards are the largest tree improvement plots in Thailand covering an area of 978 ha. There are two types of seed orchards, clonal seed orchard (CSO) and seedling seed orchard (SSO) based on the planting stock used. The majority of seed orchards in Thailand are CSOs composed of vegetative copies of selected genotypes. The first CSO was established in 1965 at Maegar seed orchard in the Phayao province. Among the orchards established by the RFD and FIO during 1965-1988 the Donglan SRS (Photo 20-6) has the biggest area (456 ha) followed by Maegae SRS (202 ha) (Table 20-3).

Table 20-3 Areas of teak seed orchards in Thailand

Organization	Year	Ha	Rai
Royal Forest Department (RFD)		785.44	4,909
Mae Gar Silvicultural Research Station	1965	202.24	1,264
Thongphapoom Silvicultural Research Station	1987	32.00	200
Donglan Silvicultural Research Station	1972	456.00	2,850
Khao Soi Dao Silvicultural Research Station	1969	23.20	145
Ngao Silvicultural Research Station	1987	8.00	50
Chaingrai Silvicultural Research Station	1988	64.00	400
Forest Industry organization (FIO)		193.12	1,207
Total		978.56	6,116

Photo 20-6 Seed orchards at Donglan SRS in Khonkaen Province (left) and at Mae gar SRS in Phayao province (right)

Genetic Conservation in the World Teak Conference 2013

The World Teak Conference held in Bangkok in 2013 recommended that

(1) Strategies of genetic improvement of teak should be formulated with greater consideration for conservation of the existing gene pool,

(2) There is a need to develop appropriate biotechnology tools that can support intensive tree breeding program.

(3) Genetic conservation programs should be developed as an integral part of tree improvement and plantation management.

(4) Delineation of provenance zones, and controlled harvest in seed production areas established in these zones, may be carried out as a priority.
(5) A re-evaluation of clone archives and existing clonal seed orchards using tools of molecular biology is recommended and the origin of land races investigated and their diversity assessed.
(6) Genetic materials and genetic exchange should be promoted to maximize production of high quality teak across the world.
(7) Innovative markets for shorter rotation teak crops may be explored to make this species more attractive to small growers.
(8) Increase new candidate trees and hybrid clones for selection for more widely uses in commercial scale and adapted to several site condition.
(9) Improved genetic materials of teak from tree improvement program should be promoted for wider usage (Tangmitcharoen, 2013).

Lessons Learned and Recommendations

Over the six decades of the teak improvement program in Thailand a number of lessons have been learned which are summarized below:

Narow genetic base

From the beginning it became obvious that narow genetic base for field testing (selecting Plus tree from limited provenances) brings ineffective results. This led to covering the whole range of natural teak distribution across the country for selecting Plus trees.

Impropered propagation techniques

Impropered propagation techniques are essential for accuracy of the clonal testing. The technique of rooted cutting was developed in place of budding technique to avoid incompatibility and wrong assessment of the rooting stock instead of the target clone.

Updated breeding strategy

Direction and timeline of long-term breeding programs should be clearly described and updated as more clones, more tests, and more techniques are added to the improvement program.

Promote the use of improved genetic material

Extension of improve genetic materials to tree farmers is essential for larger and quicker returns from investments made in the teak improvement program. Production of improved quality seeds and improved clones should be promoted to meet demand of quality seedlings and to meet standard of wood quality in national and international markets.

Conclusion

Teak genetic resources, including the recent discovery of teak at high altitude at Nawawintara Rachinee teak forests, have been well conserved in Thailand through in-situ and ex-situ gene conservation. *Ex- situ* is the key measures of teak genetic resources management in Thailand. Several forms involved with tree improvement plots such as clone bank, provenance trials, progeny test, and seed orchard have been established.

WTC 2013 has generated several valuable ideas for the genetic conservation of teak such as formulating strategy of genetic improvement, enhancing cooperation among national and international agencies, and developing biotechnology tools among others. Some of these recommendations have already been implemented in Thailand including the initiation of genomic selection in cooperation with Japan International Research Centre for Agricultural Sciences (JIRCAS) recently.

References

Changtragoon, S., Ongprasert, P., Tangmitcharoen, S., Diloksampan, S., Luangviriyasaeng, V., Sornsathapornkul, P. & Pattanakiat, S. (2012). *Country Report on Forest Genetic Resources of Thailand*. Report to FAO for SoW-FGR by Department of National Parks, Wildlife and Plant Conservation in collaboration with Royal Forest Department, Kasetsart University, and Mahidol University, Bangkok, Thailand.

DNP. (Department of National Parks Wildlife and Plant Conservation). (2020). *Increase forest area, fulfilling life, return wildlife to nature*, Bangkok, Thailand. http://portal.dnp.go.th/Content/PR?contentId=22409 (accessed 24 August 2021).

DNP. (Department of National Parks Wildlife and Plant Conservation) (2021). *Repot on Status of natural teak forest in Thailand during 2006-2020*. Forest Inventory and Assessment Division Forest and Plant Conservation Research Office DNP., Bangkok.

Hedegart, T. (1974). The teak improvement Centre: Ten years after initiation. *The Vanasarn, 32*(4), 342-356.

Kanchanaburangura, C. (1976). *Teak* (*Tectona grandis* L.) *Seedlings and provenance variation*. MSc. thesis, Australian National University, Canberra, Australia.

Kaosa-ard, A. (1981). Teak (*Tectona grandis* L.f.) it's natural distribution and related factors. *Natural History Bulletin of the Siam Society, 29*, 55-74.

Katwal, R. P. S. (2003). Teak in India: Status, prospects and perspectives. In *Proceeding of the International Conference on Quality Timber Products of Teak from Sustainable Forest Management*, pp/ 1-18. *2^{nd}-5^{th} December 2003*, Peechi, India.

Kijkar, S. (2003) Current status of teak in Thailand. In: *Proceeding of the International Conference on Quality Timber Products of Teak from Sustainable Forest Management,* pp. 68-72. *2^{nd}-5^{th} December 2003*, Peechi, India.

Kjaer D E. 2003. Genetic aspects of quality teakwood plantations. In: *Proceeding of the International Conference on Quality Timber Products of Teak from Sustainable Forest Management,* pp/ 311-320. *2^{nd}-5^{th} December 2003*, Peechi, India.

OCRP. (Office of the special commission to coordinate projects arising from the royal initiative Project) (2017). *Follow-up report on teak genetic conservation projects and improving the quality of life of people in the pai basin forests due to the Royal Initiative*. http://www.rdpb.go.th, (accessed 31 August 2021).

RFD. (Royal Forest Departemnt). (2013). *Thai teak knowledge*. Forest Research and Development Bureau RFD., Bangkok, Thailand. (in Thai).

Sumantakul, V. & Sangkul, S. (1998). Teak Resources in Thailand. In *Teak for the Future: Proceedings of the Second Regional Seminar on Teak*, pp. 211-220. FAO Regional Office for Asia and the Pacific (FAO), Bangkok, Thailand.

Tangmitcharoen, S. (2009a). Thailand consultative workshop on forest genetic resources conservation. In *Report on National Consultative Workshops of Seven Southeast Asian Countries. Forest Genetic Resources Conservation and Management*, pp. 27-156. The Asia Pacific Forest Genetic Resources Programme (APFORGEN), Malaysia.

Tangmitcharoen, S. (2009b). Status of the conservation and management of forest genetic resources in Thailand. In *Report on Forest Genetic Resources Conservation and Management: Status in Seven South and Southeast Asian Countries*, pp. 27-156. The Asia Pacific Forest Genetic Resources Programme (APFORGEN), Malaysia.

Tangmitcharoen, S. (2013). Summary from the world teak conference on genetic, silviculture and utilization. In *Proceeding of Annual Meeting on the Year 2013 Entitled "Production and Forest Research Towards Sustainable Management,* pp. 349-359. *5th-9th August 2021*, Royal Forest Departemnt (RFD), Bangkok, Thailand.

UNESCO (United Nations Educational, Scientific and Cultural Organization) (2019). *Hauy Tak Teak Biosphere Reserve*, Thailand. https://en.unesco.org/biosphere/aspac/hauy-tak-teak (accessed 23 August 2021).

Verhaegen, D., Ofori, D., Fofana, I., Poitel, M. & Vaillant, A. (2005). Development and characterization of microsatellite markers in Tectona grandis (Linn. f.). *Molecular Ecology, 5*, 945-947.

Chapter 21: Progress in Teak Improvement Program in Thailand

Chumnun Piananurak

Abstract

Teak genetic improvement in Thailand began in 1965 under a bilateral agreement between Thailand and Danish governments. Plus tree selection is the first and most important step in genetic improvement program. Guidelines for selecting and criteria for selection were set up based on of four aspects of growth, stem form, wood quality, and the health of the tree and a total of 636 Plus trees were selected. Of these 509 Plus trees were planted in 5 clone banks across the country. Since in selecting Plus trees only phenotype is evaluated clonal tests are needed to evaluate genotypic characteristics. Three sets of clonal test were conducted, the first one using budding techniques for propagation for 100 clones and tested at one site. Second set of clonal test was conducted using rooted cuttings for vegetative propagation for 400 clones at 4 sites. The last set of 100 clones has recently been established as part of the ITTO-Mekong Teak project in 2021. For improved teak seeds Clonal Seed Orchards have been set up using 256 Plus trees.

Progeny tests using full-sib progeny and half-sib progeny were employed to identify trees of better genetic quality. These high-quality teak seeds are now available for use by farmers for producing high quality teak timber.

Introduction

Thailand started its teak improvement program under a bilateral agreement between Thailand and Danish governments in January 1965. A teak improvement center, known as Ngao silvicultural research station, has been established in the Ngao District in Lampang Province in the Northern part of the country to run teak improvement program under this project. At the beginning of the project some Danish experts were assigned to work closely with Thai researchers. They helped set up the teak improvement program for Thailand as shown in the flow chart (Figure 21-1) which is used as a step wise guidance for teak improvement in the country. The progress of each step is reported here in this article.

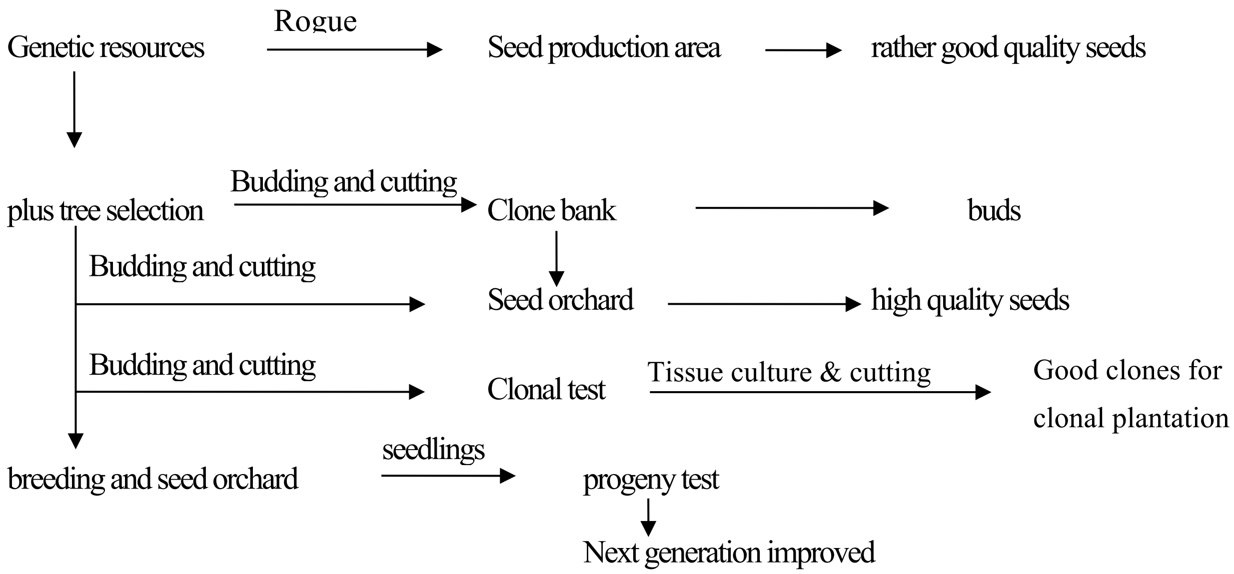


Figure 21-1 Teak improvement program in Thailand (Kaosa-ard & Chanpaisaeng, 1992)

Plus Tree Selection

Plus tree selection is the most important step. If the selection is wrong, it will ruin the whole program so the plus tree must be intensively selected. The selection of the plus tree is aimed at getting the highest possible genetic gains in quickest possible time and at least cost while maintaining a wide enough genetic base to ensure that the genetic gains will continue to increase over generations.

In selecting mother trees for breeding, the same principle is used to select trees with wanted characteristics. The selected trees are then used as parents in breeding and production of good quality seeds based on the hypothesis that parents with good genetic traits will always pass good traits to their offspring.

Some important advantages of using selected plus trees in the forest plantation work.

1. Trees in plantation have a good shape, straight stems with few knots, which make the cost of logging for hauling and transporting cheaper.

2. Lowered losses during processing and manufacture.

3. Rotation is shortened because the trees grow faster, resulting in a faster return on investment.

4. Reduces investment in planting as trees can be planted at wider spacing.

5. This makes investments in consequence industries less cost.

6. Get better wood quality such as high density and straight wood grain etc.

Forest breeders should choose only the most important characteristics in selection of plus trees, namely, high economic values and positive correlation with other traits. Characteristics that are commonly taken into consideration when choosing a plus tree are good growth, round stems, branches that prune naturally and are medium to small compared to the stems in proportion and shape, good resistance to diseases and insects, resistant to drought conditions, resistant to cold conditions, late flowering, good wood quality. Sumantakul (1999) has set up guidelines for selecting Plus trees as follows:

1. Choose a forest stand or a forest plantation that consists of trees that are naturally tall and well grown, most tree trunks are round and straight, branches are

naturally pruning and perpendicular or nearly perpendicular angles to the trunk. It may be called a Plus stand.

2. The Plus stand should be located in an area with conditions similar to the area that future forest plantation will be planted.

3. Do not choose from plantations that use seeds from sources that are not well adapted to the environment where plantations are to be raised in future.

4. Selection should be from a tree stand that is largely of the same species.

5. The selected trees stand should not have been logged before and forest plantation that has been thinned should not be selected except for mechanical thinning.

6. The size of the plus stand is not limited, but it must contain enough candidate trees and comparison trees.

7. Only one mother should be chosen if the group is small. This is to avoid inbreeding of the selected mother trees.

In Thailand, the criteria for selection consist of four aspects. First is growth which is diameter at breast high, and height especially commercial height. In natural stand, the set standard is at least 15 meter commercial height but in plantations it may be shorter. Second is stem form which are clear bole, small branches, straight axis and low buttress. Third is wood quality for which it would be good to check wood color and density by using wood borer and pylodyne. Wood grain is usually indicated by bark pattern with straight strip bark pattern indicating straight wood grain inside. If it is spiral bark the wood grain will be twisted. The last is health of the tree. Around the candidate tree it must be checked that there is no sign of pest and disease. Sumantakul (1999) suggested using a scoring method and set up standard guide line to select plus tree using tree selection form in which information of each plus tree is recorded.

The plus tree selection of teak is done in dry season when the forest is easier to walk through and it is clearer to look at the tree form. Other reason is that in dry season the buds start to sprout which is the most suitable stage to be grafted. It is difficult and costly to go to the forest to get to the plus trees again and again and, therefore, the branches of Plus trees must be collected during Plus tree selection process itself and taken back for propagation to conserve their genetic materials. Clone number, called V number, are given during selection itself for each tree, information are recorded in Plus tree record form and photograph are taken. While taking photograph V number is placed on a sign board on the tree and genetic materials taken from each plus tree is labeled accordingly.

Clone Bank

Up to now a total 636 Teak Plus trees have been identified and numbered in Thailand under the teak improvement program. The Plus trees are scattered in areas which are mostly difficult to access, such as deep forests, on mountains with no road access. Each plus tree is far away from each other. After the selection program is over, it is difficult and inconvenient to return to do seed or scion collection. In addition, most of the selected trees are good quality and, therefore, specially prone to illegal felling causing the loss of selected trees. So it is wiser to take genetic material of plus trees to plant at a safe place that called "Clone Bank" which serve as multiplication garden as well.

Objectives of clone bank.

The establishing a clone bank of teak plus trees has the following objectives:

1. To conserve Plus tree genetic material in safe places.

2. To conserve teak Plus trees genetic material from around the world to be used as genetic resource whenever needed. The genetic resource can be used for further improvement program such as in seed

orchard, clonal test, or even planting a forest plantation.

3. To act as multiplication garden where branches of Plus tree can be taken for propagation and used for further improvement program avoiding the need to go back to the forest for Plus tree genetic material.

4. To copy all genetic traits of plus trees by using vegetative propagation.

5. To conserve not only teak plus trees but also some that have a special history, such as a biggest teak in the world, or teak that is resistant to insects or pests.

6. To facilitate the management of selected Plus trees.

Establishment and management of clone bank

Planting materials are from vegetative propagation like budding or cutting. Spacing 2x2 m^2 is suitable with same clone planted in the one row. Usually, 10 propagates per clone are planted.

1. The branches taken from plus tree are propagated by budding in nursery in order to rejuvenate the materials. The rejuvenile shoots are then propagated by rooted cutting.

2. Planting seedlings in rows, one row for one clone and each row contains about 10 seedlings (ramet). Lay out of clone planting should follow sequence number for ease in future management. Spacing of 2x2 meters is convenient for operational reasons.

3. It is important to emphasize that in front of each row, a ferroconcrete post is buried leaving about 50 cm. above ground and on each such post the V no. of the Plus tree is carved. Wooden posts are not suitable as they tend to degrade early.

4. Maintenance of the garden by watering, weeding, fertilizing is carried out as in ordinary plantation. In the case of budding technique for propagation, paint (preferably red or bright) is used to mark the part of the trunk where stock and scion are joined. Regular monitoring is done and shoots that sprout below the joint are removed. This activity must be carried out every year.

5. Trim the canopy to make the stems shorter and produce more branches. This is for the convenience of collecting branches and maintaining juvenility of the bud, which improves the ability of vegetative propagation. This needs to be carried out at least once a year.

Table 21-1 Information about Clone Banks in Thailand

No.	Location#	Area (ha.)	No. of clone*	Established year
1.	Ngao SRS	5.76	396	1965-2019
2.	Maegar SRS	0.5	113	2002-2003
3.	Phitsanulok SRS	4.00	438	2009
4.	Donglan SRS	4.00	438	2009
5.	Thongphapoom SRS	4.00	438	2009

#SRS stand for Silvicultural Research Station *Same clones were planted at many sites.

Information on the clone banks is presented in Table 21-1 above. The total number of clone in clone bank is 509 clones. All the 636 Plus trees are not represented in the clone banks as some plus trees were discarded during reselection or died during propagation.

Photo 21-1 illustrates concrete post in front of every plant row indicating clone number and management by pruning every year. Trees in the clone bank are bushy because they are cut every year. There are 5 clone banks in Thailand as shows in Table 21-1. The original clone banks were planted in Ngao SRS and Maegar SRS in the north of the country. In 2009 three more clone banks were established at Phitsanulok SRS, Donglan SRS, and Thong phapoom SRS in different parts of the country to reduce the risk of loss of precious genetic material.

Photo 21-1 Clone bank at Mae gar SRS

Clone Test

The clonal test is one of the important tasks of teak improvement program. The test aims to evaluate the genotypic value of the Plus trees for breeding and further propagation. When we select Plus trees we can see only phenotypic traits of the trees. Phenotype is the observable physical characteristic of a tree determined by the genotype interacting with the environment in which it is grown. In clonal test the objective is to evaluate genotypic value of Plus trees by planting in the same environment. Thus the comparative phenotype across Plus trees observed in clonal test is controlled by genetics alone. We also evaluate genotype and environment interaction on plus trees by testing at many sites. Plantlets from different Plus trees are taken through vegetative propagation and then planted together for testing in the same area. The test can be conducted in many sites to evaluate genotype and environment interaction.

Objectives of teak clonal testing

1. To select the best individual for further improvement step or to build a seed orchard or clonal plantation.

2. To assess the genotypic value of existing Plus trees or clones to be used as indicators for re-selection the Plus trees and perform genetic thinning primarily in the teak seed orchard.

3. To assess broad-sense heritability and to study genetic correlation between characters of teak from the tested clones.

4. To assess the genotype and environment interaction of the existing plus tree or clones in order to be used as an indicator for the selection of suitable clones for planting teak clonal plantation, either locally or in multiple sites.

How to conduct teak clonal test

The plantlets used in the test must be asexually propagated. A suitable method is the rooted cuttings although tissue culture is possible but is not preferred because it is more expensive. The test area must be located in at least 3 different sites in order to explore the genetic and environmental interactions. Planting in randomized complete block design consists of 100 treatments (Plus trees), 3 sites with each site having 4 replications and each replication consisting of 3 plants. Plus trees from the same source are not placed close to each other because if the experimental plot is later modified to a clonal seed orchard, Plus trees from the same source will spread throughout the plot. The total number of trees planted in each site in Thailand is 1,200 trees, using a spacing of 4 x 4 m, with the buffer zone was planted with 2 rows of teak trees surrounding the plot.

After the test plot has been planted, check the survival percentage during the first three months and replant once every month. Maintenance of the plots involves weeding twice a year, rigorous fire protection and forest fire prevention. Measurements of growth in diameter and height are recorded every year. Final evaluation is performed at the age of 20 by measuring growth and shape which consists of straightness of the trunk, rupture of the trunk, branching characteristics, size of branches, flowering, as well as the health traits including survival and stem damage.

Teak clonal test in Thailand

The timeline of teak clonal test in Thailand can be summarized as shown in Figure 21-2. From the timeline and information shown, the test can be divided into 3 sets.

First clonal test was planted in 1988 using budding as the propagation technique. Testing was conducted at Ngao SRS. The treatment was 100 clones with 6 replications of 2 trees plot. Planting spacing was 3x3 m. Some superior clones from this test were used for clonal propagation, for plantation and for selecting mating-pairs in full-sib progeny test. There are controversies about budding technique used for this test since the root system does not belong to the tested clone. Root system plays an important role in the tree growth and, therefore, growth of the tested trees is not affected solely of the clones themselves.

Second set of clonal test was done using rooted cutting of teak once the practice had been practiced and well documented (Pianhanurak et al., 1996). It was established at 4 sites at Thong Pha Poom SRS, Kham Phang Phet SRS, Song Khla SRS and Ngao SRS. Each site has 4 sub-sets planted in 2000, 2001, 2003 and 2006 except Ngao SRS that has only 1 sub-set planted in 2005. Propagation technique used was budding for rejuvenation from which shoots were taken for rooted cutting. Each sub-set testing plans are the same except for testing different clones. The treatment was 100 clones with 4 replications of 3 line plot. Planting spacing was 4x4 m. Planting design of every set is CRBD.

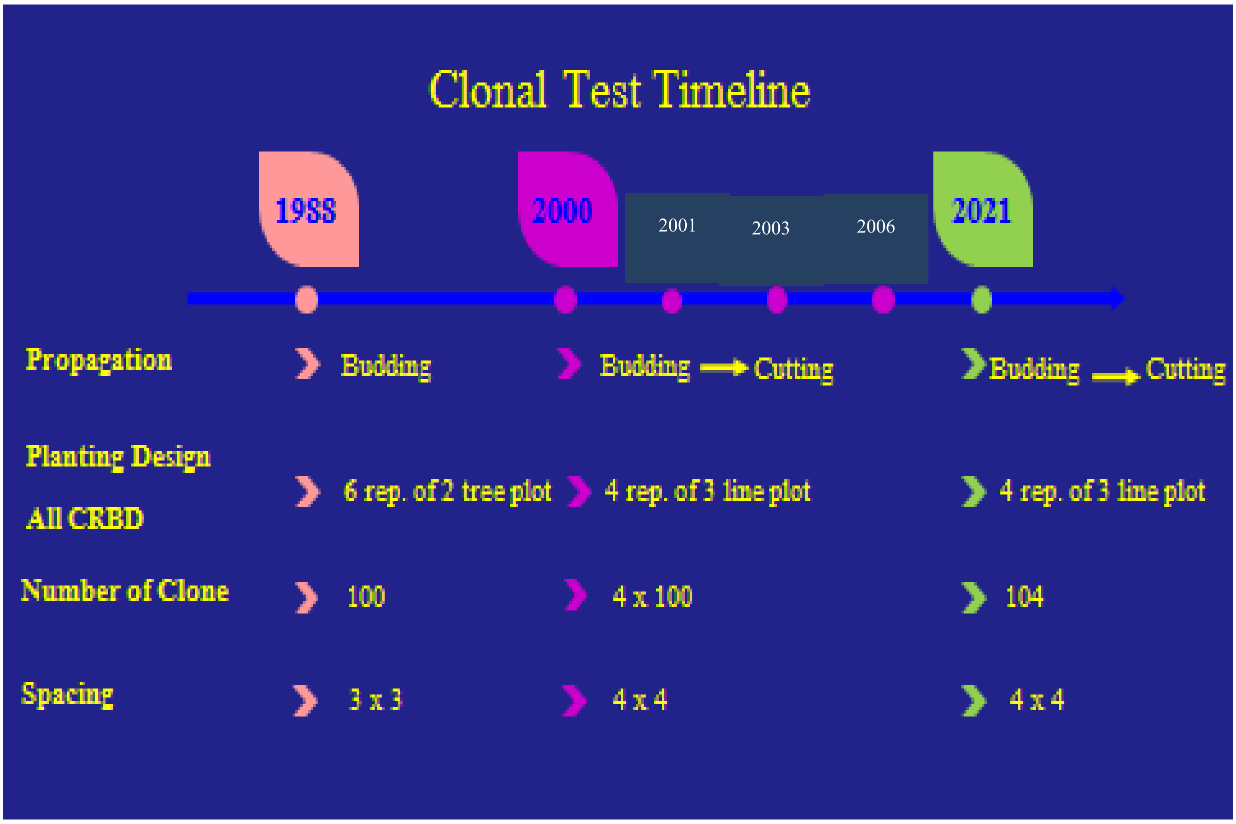


Figure 21-2 Teak clonal test timeline and the testing information

The 2000 test plots at 3 testing sites, namely, Kanchanaburi, Songkhla and Kamphangphet were evaluated twice at 5 and 10 year age (Anon, 2013). One testing site could not be evaluated due to fire damage. The first result at 5 years old showed that height and DBH of tested clones were statistically significantly different at different sites establishing the effect of interactions between site and clone on growth of plants. The second results at 10 years age confirmed the preceding evaluation by showing the same results. There were only 2 stable clones that grew well at all sites. The 5 best clones in each site were separately selected to be the suitable clones for promotion among farmers.

Another set, sponsored by the ITTO Teak in Mekong Project, was planted in 3 sites at Thung Kwian, Krengkawia plantations and Donglan SRS in 2021. Propagation technique used was budding for rejuvenate materials followed by taking the shoots for rooted cutting. The tested clones consist of the clones which have not been tested in the second set in addition to 10 superior clones selected in the 2000 test. The treatment was 100 clones with 4 replications of 3 line plot. Planting spacing was 4x4 m. Planting design of every set is also CRBD. The locations of clonal tested sites are shown in Figure 21-3.

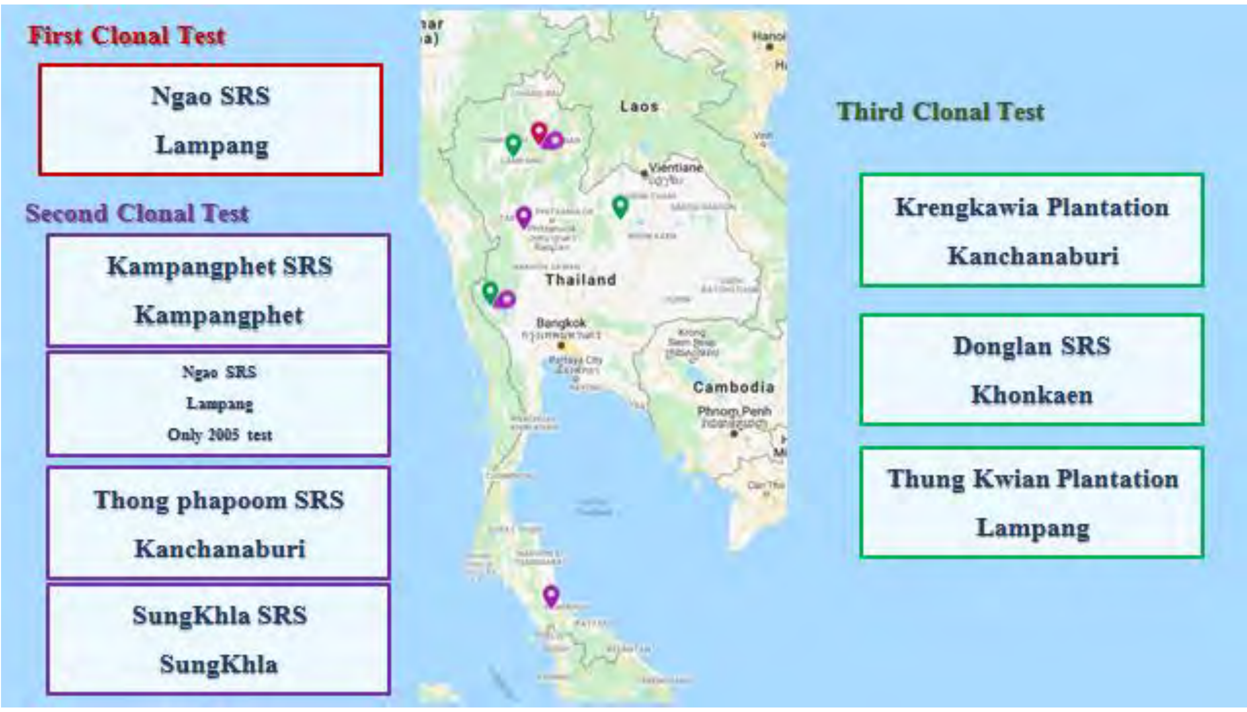


Figure 21-3 Locations of 3 sets of clonal tests of teak plus trees

Seed Orchard and Breeding Orchard

Establishing a seed orchard is a continuation step from the selection of Plus trees by bringing the selected father and mother plants to an orchard to produce good seeds. A seed orchard is defined as an area where seeds are mass-produced to increase the genetic quality as quickly and inexpensively as possible (Zobel et al., 1958). It is a plantation of trees with the requisite genetic characteristics planted at a distance from natural or planted forests of the same species. It is managed to achieve high and consistent seed yields that are easy to harvest.

Seed orchards can generally be divided into two types: clonal seed orchards and seedling seed orchard (Zobel et al., 1958). A clonal seed orchard is a seed orchard created by using plantlets from asexual propagation such as budding, cutting or grafting from selected plus trees. Trees in the orchard inherit all the genetic traits of the mother trees. Each seed orchard would not be less than 50 clones and planted by random planting positions (Sumantakul, 1999). A seedling seed orchard is a seed orchard created by using seedlings collected from the selected Plus trees. At present only clonal seed orchards have been established for teak in Thailand.

Characteristics of teak seed orchard

The teak seed orchard must have the following characteristics (Khaosa-ard, 1983):

1) Seedlings used in clonal seed orchard must be selected clones propagated by asexual method.

2) A seed orchard must have a layout map showing the number of clones planted as well as their locations in the orchard.

3) In a seed orchard the plant spacing should be more compared to normal forest plantation to allow the trees planted to fully expand their canopies to maximize seed yield. For teak, the spacing used is generally 10 x 10 meters.

4) A teak seed orchard should be at least 1 to 2 km away from natural teak forest and teak plantations to prevent cross breeding by pollen from outside the orchard.

5) Establishing a seed orchard requires special care compared to a general forest plantation. Fertilizers may be applied to accelerate tree maturity to hasten fruiting as well as increase seed yield. Weeds should

be cleared to make it easier to collect seeds, insect and disease control measures should be undertaken.

6) In Thailand collecting of seeds in seed orchard is done by climbing up and collecting from individual trees. Seed collection is usually done in February before seed fall. Seed extraction and cleaning are carried out manually by beating, sieving and grading.

Data collected on location, topography, meteorology, planting method, tree growth, orchard management, seed production, seed quality, and soil properties of clonal seed orchards (CSO) in Thailand and reported in Piananurak (1995) is presented in Table 21-2. There are 22 CSOs in Thailand hosting a total of 256 clones. Six of these CSOs are under the administration of Royal Forest Department while the rest fall under the control of the Forest Industry Organization where no seed collection is being done at present.

Table 21-2 Information of CSO in Thailand

Sr.	Name of CSO	Area (ha.)	No. of clone	Seed productivity (Kg/yr)	Established year
1.	Mae Gar SRS	175	193	950	1965
2.	Lansang SRS	127	44	-	1965 (canceled due to low viability)
3.	Khaosoidown SRS	372	88	1,000	1969
4.	Donglan SRS	408	51	600	1972
5.	Maetha SRS	528	40	0	1974 (later changed to SPA)
6.	Chiang Rai SRS	8	100		1987
7.	Maemy Plantation	7	22	*	1967
8.	Khaokrayang FIO Plantation	9.6	34	*	1967
9.	Thungkwian FIO Plantation	12.8	7	*	1968
10.	Maejang FIO Plantation	8	15	*	1968
11.	Maemoh FIO Plantation	7.68	16	*	1969

Sr.	Name of CSO	Area (ha.)	No. of clone	Seed productivity (Kg/yr)	Established year
12.	KhunMaekummee FIO Plantation	8	12	*	1969
13.	Maehorphra FIO Plantation	17.6	13	*	1971
14.	Maesaikum FIO Plantation	16.8	41	*	1971
15.	Maelee FIO Plantation	14.4	65	*	1972
16.	Ban Danlanhoi FIO Plantation	16	26	*	1974
17.	Maejam FIO Plantation	2.88	26	*	1975
18.	Maelamao FIO Plantation	19.2	16	*	1975
19.	Wangchin FIO Plantation	16	41	*	1977
20.	Maesroi FIO Plantation	16	9	*	1978
21.	Thapla FIO Plantation	12.8	30	*	1978
22.	Thai Plywood Co. Plantation	6.4	25	*	1985

*No seed collection

Breeding orchard

Breeding orchards are established for the creation of new cultivars for offspring selection along with the establishment of a clonal test for re-selection of mother plants. The objectives of breeding orchards are as follows:

1. To be used for random mating within each parent group (sub-populations) and create new breeds of teak in the coming generations.

2. To produce seeds for raising plantations for testing or for breeding control and collecting seeds for testing.

According to the teak breeding strategy of the project, breeding operations are divided into 5 groups or sub-lines of 100 clones each, with a total of 500 clones for breeding purposes. The sub-lines will used to create a breeding orchard. Genetic thinning of seed-breeding orchards is performed twice for 50 % of the existing mates using the results of clonal test and of breed testing through open-pollinated progeny test as shown in Table 21-3.

Table 21-3 Evaluation and genetic thinning plans of teak breeding orchard in each plot (block)

Age (years)	number of clones	number of plants/rai	Area/plant (m^2)	Spacing (approximately) m^2
1	100	32	50	7.1 x 7.1
12	50	16	100	10.0 x 10.0
28	25	8	200	14.1 x 14.1

Genetic thinning at 12 years (50%) was based on the results of a clonal test. Genetic thinning at 28 years (50%) using the results of a progeny test of 50 mothers (clones/families)

Accomplishment in establishment of breeding orchard

Teak breeding orchards were set up in 5 areas in 1988 of which only 4 areas (consisting of six plots) survive today at Ngao SRS, Mae Gar SRS (2 plots), Khao Soi Dao SRS and Dong Lan SRS (2 plots). Planting design for breeding orchards uses a Randomized Complete Block Design (RCB) with each test plot consisting of 100 clones in 6 blocks and in each block planting was done at a spacing of 7 x 7 meters (total 600 plants per garden).

Progeny Test

While selecting Plus trees only externally observable characteristics, or phenotype traits, are used and the genetic value of the tree, and how much of the good traits can be passed on to offspring, are unknown. Assessment of the genetic value of the mother tree can be done through the progeny test. It is a test to compare the offspring of different parents. This test is used backwards for reselection of the mother or parents. Once the best parents are identified forward selection is carried out by choosing the best individuals out of the test. The best individuals are then made available to the farmers for raising clonal plantations. There are two types of the progeny test. One is half-sib, or open progeny test, with pollination occurring due to wind or insects and with only mother side known. The other is full-sib progeny test which pollination is controlled and both of parents are known.

Half-sib progeny test conducted in Thailand.

Results of half-sib progeny trials conducted earlier in Thailand were not very promising primarily due to limited number of plus trees most of which were from the same provenance. Damage to the trees caused by forest fires further made the evaluation impossible.

These limitations were addressed appropriately and half-sib progeny tests were conducted again. Planting material for the test were seeds of 295 families from 180 Plus trees collected from CSOs at Maegar SRS, Donglan SRS and breeding orchard at Ngao SRS. Seeds of the same Plus tree number but collected from different CSOs were considered as different families. In addition, tissue culture plantlets from 3 plus trees, and seedlings from 2 plus trees were also used as planting material for these trials. Planting was done at 4 sites in the beginning, but the Lansang SRS site was discarded subsequently due to poor survival owning to prolonged drought. Only 3 sites at Intakhin SRS in Chiang Mai, Donglan SRS in northeastern, and Bantakhun SRS in southern were left from where experimental data was collected. The evaluation is yet to be completed.

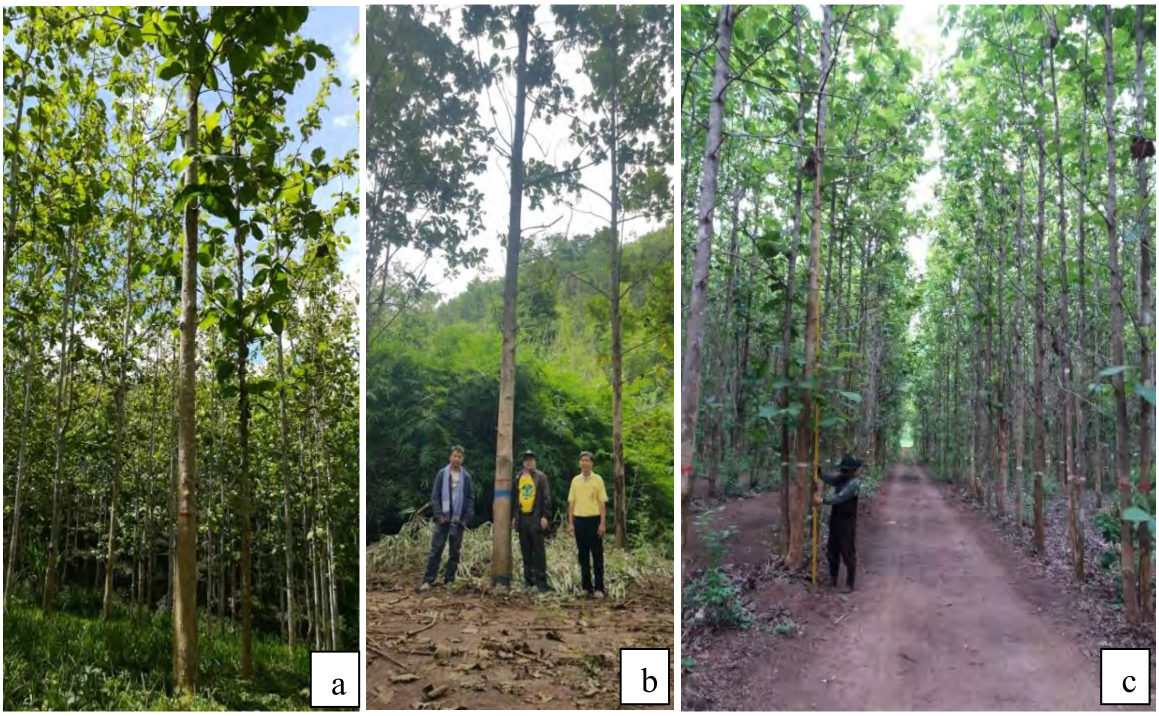


Photo 21-3 Performance of 8 year-old teak trees in half-sib progeny test plots at a) Bantakhun SRS, b) Donglan SRS, and c) Inthakhin SRS

Information and outcome expected from this test are as follows.

Quantitative Inheritance: Population parameters that could be evaluated are Mean, Variance, Standard deviation of the Population, Phenotypic value, and Genetic value.

Heritability: Broad-sense heritability, Genetic gain.

Genetic Combining Ability (GCA): From this value, the genetic worth or breeding value of the mother could be evaluated.

Clonal Planting Materials: Forward selection of individual elite trees from the test plots could be done for promoting clonal plantation.

Seedling Seed Orchard *(SSO).* After all data collection, the testing plots could be converted to SSO.

Full-sib progeny test

Full-sib progeny test is the test which both of parents are known by performing control pollination. The test aims to use characteristic of progeny to evaluate breeding value of their parent. From this test not only Genetic Combining Ability (GCA) and additive genetic variance of the parent but also Specific Combining Ability (SCA) can be calculated. Better parent are the parent with higher ability to transfer desired characteristics to their offspring. The parent will then be selected in further improvement program. At the same time some progenies that perform better than others in the trial could be selected and vegetative propagated for clonal plantation with higher genetic value.

Control pollination -

Control pollination is pollinating the female flowers of a tree with pollen from a known source, usually one specific tree. Usually the flowers are protected from undesirable pollen by covering them with a pollen-tight cloth or paper bag before they are receptive and adding known-source pollen at receptivity.

Full-sib progeny test in Thailand.

Two sets of full-sib progeny were conducted. First set was conducted in 2006 with full diallel mating design of 5x5 pairs with reciprocal. One side parent was of

Lampang origin while the other was from outside Lampang (Chiang Mai and Maehongsorn Provinces). A total of 50 families from controlled crosses and 4 from open pollinated for comparison were planted in 2007 at 4 different sites with contrasting soil and climatic characteristics. The experiment was set up in a randomized complete block design with 4 replications of 3x3 plants each family at spacing 4x4 meter. But only two sites at Phitsanulok SRS, Phitsanulok Province and Dong Lan SRS, Khon Kaen Province could be used to obtain growth data. (Wattanasuksakul et al., 2013). First evaluation was reported at 5 years age and presented at the world teak conference held in Bagkok. It was concluded that growth of progenies was significantly affected by sites and Donglan proved a better site than Phitsanulok. There were significant male and female interaction effects on growth of teak progenies planted at Donglan when Plus trees from Lampang were female. Reciprocal effects occurred in one case at Phitsanulok site. Significant effect on DBH growth of progenies was noticed when Plus trees from outside Lampang were male but none while being female. At 5 year old teak progenies were too young to evaluate their parents in term of heritability, GCA, and SCA (Wattanasuksakul et al., 2013). Backward reselection is now under the process of calculation and evaluation. Improved genetic material has already been made available to the farmers.

The second set was conducted in 2008 with partial diallel mating design of 4x4 pairs of plus trees from Phrae, Mae Hong Sorn, Lampang and Chiang Mai. Trees from the same origin were not mate and only one way crosses were conducted. A total of 12 families were planted in 2010, at 4 different sites with contrasting soil and climatic characteristics, but only 2 sites at Phitsanulok SRS, Phitsanulok Province and Dong Lan SRS, Khon Kaen Province could be obtained data. 3 sets of experiment were set up in a randomized complete block design with 4 replications of 3x3 plants each family at spacing 4x4 meters. The evaluation is yet to be completed.

Lessons Learned and Recommendations

1. Breeding of mother trees regardless of their sources or cross breeding a closely related tree may result in a breed with inferior characteristics. Therefore, before breeding, it is necessary to examine parent's history thoroughly to avoid such problems.

2. For half-sib progeny test when many mother trees are tested, forward selection may be done by thinning bad families and keeping desired families to create second generation seedling seed orchard (SSO). When creating the SSO by this technique, it has to be ensured that no tree of the same family stand next to each other which must be planned in advance when establishing the progeny test.

3. Mother trees with high Genetic Combining Ability can be selected to be mating pairs for conducting full-sib progeny test and finding their Specific Combining Ability.

4. Since improvement program of teak takes a very long time and process cannot finish within one generation, team work of many generations is a key to keep the process running continuously and correctly. This requires a detailed protocol to be established for passing on information and experiences from one batch of researchers to the next.

5. There are many testing plots such as clonal tests planted in 2001, 2003 and 2006, half-sib progeny test, and full-sib progeny tests had been established and well maintained but have not yet evaluated and utilized. Reports on these trials should be done as soon as possible and benefits by way of improved planting stock made available to the farmers at the earliest.

6. Results from these ongoing trials should be used to establish protocols for genetic thinning in the seed orchards to further improve the quality of seed sources.

7. It would be best to start the tests with at least 4 testing sites to evaluate genetic and environment interaction effects because in long term research work like this it is not unusual to lose some testing sites to factors beyond the control of the Forest Department.

Conclusion

In this teak improvement program set up almost six decades back in1965 as many as 636 Plus trees were selected throughout the forests where the resource is distributed and a total of 509 clones of plus trees have been planted in clone banks at five sites. Three sets of clonal test of almost 500 clones have been conducted at various sites during this period and both half-sib and full-sib progeny tests have been conducted. But several of these tests have not yet been evaluated and utilized for further use. This requires immediate action so that the full benefit of the teak improvement program may become available to all stakeholders at the earliest.

References

Anon (2013). *Thai Teak Knowledge*. Forest Research and Development Bureau, Royal Forest Department, Ministry of Natural Resources and Environment, Bangkok, Thailand.

Kaosa-ard A. & Chanpaisaeng, S. (1992). *Teak Breeding Strategy in Thailand*. Forest Research Bulletin No. 2 May 1983. Silvicultural Research Sub-Division, Royal Forest Department, Bangkok, Thailand.

Kaosa-ard, A. (1983). *Nursery Techniques Teak*. Forestry Review, Vol. 2. May 1983. Silvicultural Research Sub-Division, Forest research Division, Royal Forest Department, Bangkok, Thailand.

Pianhanuruk, P. (1995). *Analysis of Teak Seed Orchards in Thailand*. MSc. thesis, Kasetsart University, Bangkok, Thailand.

Pianhanuruk, P., Piyaphan, P. & Pianhanuruk, C. (1996). *A Preliminary Study of Rejuvenation of Teak by the Budding Technique*. ASEAN Forest Tree Seed Centre, Saraburi, Thailand.

Sumantakul, V. (1999). *Introduction to Forest Tree Improvement*. Technical publication on silviculture. Year 1, Volume 2. Silvicultural Research Division, Forest research office, Royal Forest Department, Bangkok, Thailand.

Wattanasuksakul, S., Pianhanuruk, P., Pianhanuruk. C., Krongkitsiri, V. & Chuayna, C. (2013). First evaluation of teak (*Tectona grandis* L.f.) full-sib progeny test In *World Teak Conference 2013 at Centara Grand*, Bangkok, Thailand. (Poster session)

Zobel, B. J., Baber, J., Brown, C. L. & Perry, T. O. (1958). Seed Orchards, Their Concept and Management. *Journal of Forestry*, 56(11), 815-825.

Chapter 22: Clonal Teak for Sustainable Plantation Establishment

Doreen K.S. Goh

Abstract

Dwindling supplies of teak timber from natural teak forests have caused a major shift to demand from plantations that are primarily from seedling material with unpredictable yield and quality. Rotations longer than 25 years are no longer commercially viable when a fast return is expected. The clonal option seems to be the best and most judicious way to maximize returns on investments in the shortest possible time using selected outstanding genotypes planted on suitable sites. The greater the selection intensity for quality traits in planted teak, the higher will be the commercial gain. However, emphasis must also be placed on circumventing the risks of biodiversity loss associated with cloning by maintaining a broad-based genetics resource. Based on these aspects, YSG and CIRAD jointly collaborated on a genetic improvement program for teak focusing on the development of nursery and tissue culture propagation technologies in the early 1990s. The cloning process for the multiplication of nursery cuttings and tissue culture plants has proven to be highly successful from the laboratory to the field-planting stage, leading to the worldwide exportation of clonal teak to countries across four continents. This overview of the work undertaken by YSG Bioscape in the selection, mass production and dissemination of clonal teak for multiple purposes, in particular, on the establishment and upkeep of genetically diverse clonal plots, provides strong evidence for the long-term sustainability of teak.

Introduction

Among the many high value timber species today, teak is one of the most sought after for its durability, versatility and aesthetic features. Over the past two decades, the decline in teak logs from natural forests due to export ban, over-harvesting, deforestation, and conversion to other land uses has resulted in a major shift to the establishment of fast-growing, smaller dimension and shorter rotation plantations. Traditionally established from seed sources, these plantations are estimated to cover between 4.35 to 6.89 million ha (Kollert & Kleine, 2017). Although substantial programs were undertaken by many countries to improve the timber quality of planted teak forest, constraints such as the time required for breeding work, and the unknown origin and quality of seeds resulting in highly variable and unpredictable yields, have remained (Kjaer & Foster, 1996; Chaix et al., 2011; Callister, 2021). Equally limiting are other propagation methods - grafting, layering and controlled pollination of selected parent trees, as these could not be efficiently applied on an operational scale (Monteuuis & Ugalde, 2013).

With the increasing involvement of private investors looking for the best returns in the shortest delay in Africa and Latin America, the prospective use of clones for plantation establishment offers an attractive alternative. It was based on these observations that the Forestry Department of the Sabah Foundation Group in Sabah, Malaysia, and that of CIRAD, France, decided to jointly embark upon a teak improvement program in 1989. The tissue culture facility known then as the Plant Biotechnology Laboratory (PBL), was a pilot project set up in 1992 aimed initially at the *in vitro* culture of three large-caned rattans species.

However, focus was later shifted to teak due to its higher economical value and market demand. Within a few years, research comprising of both nursery and tissue culture techniques using stem cuttings, nodal explants and meristem cultures from selected mature standing trees were developed. This was followed by field verification of the rooted cuttings and *in vitro*-issued micro-plants, then by advanced studies with CIRAD on DNA fingerprinting and Wood analyses, and finally, the commercial production of these clones (Goh et al., 2007). The next decade saw the dissemination of a few million quality-planting materials without any compromise in the phyto-sanitary requirements of importer countries, leading to the possibility of large-scale establishments of clonal teak plantations in many locations across four continents. The chapter highlights the evolution of PBL, a small research and development unit into a full-fledged commercial subsidiary of the Sabah Foundation Group, known today as YSG Bioscape over a span of more than two decades.

The Teak Cloning Process

Selection and Production of clones for in vitro culture

Cloning is defined as a way of duplicating selected trees unlimitedly by asexual or vegetative propagation methods while preserving their original genetic make-up. The outstanding and economically important characteristics that can be observed, such as fast growth, clear bole, minimal branching, pest and disease-resistance, and straightness are maintained in the resulting offspring (Zobel & Talbert, 1984; Ahuja & Libby, 1993). Thus, it follows that the greater the selection intensity for quality traits, the higher will be the commercial gain or returns for the investors (Goh et al., 2007).

Prior to the start of the joint project, seeds obtained from the Solomon Island in the late ‘80s to early ‘90s by an officer of the Sabah Foundation were grown at the Luasong research center in Sabah, Malaysia. Cuttings were obtained from these trees for developing the nursery technique after which these cutting-derived trees were planted in a demonstration plot at the same location. It was from eight of these standing trees that the initial plant material was obtained and used for the development of the cloning process (Photo 22-1). Likewise, plant materials of other teak origins or sources found in Sabah were also collected for *in vitro* culture with the intention of doing comparative studies of the different clones under the given tissue

The explants arising from young shoots and herbaceous branches collected from mother trees are cleaned and disinfected in a series of steps to remove existing microorganisms such as bacteria or fungi. These are then trimmed into 2 – 3 cm segments and cultured on a single elongation-multiplication culture medium using a minimal concentration of growth hormone for 3 - 4 weeks until the development of axillary bud-produced microshoots is observed (Photo 22-2) (Monteuuis et al., 1998; Goh & Monteuuis, 2001). Once these elongating shoots have produced a minimum of 2 pairs of leaves, these are excised and placed on fresh culture medium for the subsequent stabilization phase, and the new plant is monitored on a daily basis. Upon attaining a height of 4 to 6 cm, the microshoot is cut into 2 to 3 cuttings, each with a pair of leaves from where new axillary shoots will in turn be produced. This stage constitutes the first multiplication cycle and the process is repeated at every 6-8week interval depending upon developmental rate of each clone. The procedure for meristem culture is similar to the micro-cutting method except for the size of the explant. Although requiring more skill and expertise than for nodal explants, shoot apical meristem- averaging 0.1-0.3 mm in size – culture is more efficient for rejuvenating mature genotypes while overcoming the contamination problems that commonly affect the primary cultures (70% versus 20-30%, respectively). This technique is

therefore becoming more frequently used for our new introductions of mature genotypes selected from the field.

Photo 22-1 Herbaceous shoots are collected for in vitro culture from standing mother trees selected based on outstanding morphological traits

Photo 22-2 Contamination-free and responsive nodal explants giving rise to axillary microshoots that will be used for subsequent multiplication under optimal tissue culture conditions.

The developed *in vitro* technology for microcuttings, with the possibility of an exponential multiplication rate of 3 -4 cuttings per plantlet at each cycle, was simple, low-cost, and observed to be suitable for all genotypes regardless of the age of the mother tree (Monteuuis, 2000). Although 50 to 60% of the microcuttings can root spontaneously in the sole multiplication-elongation culture medium during the production phase, the acclimatization-rooting phase is achieved in nursery conditions under a mist system with over 95% success on average in the absence of any rooting substance treatment. It is also noteworthy that despite the success derived from the nursery rooted cutting technology, the production of plants under optimal *in vitro* conditions is overall more efficient in that it can be undertaken whole year round, require minimal space for large quantities production, and meet phytosanitary requirements for overseas exportation. The laboratory currently has a production capacity of 1.5-2 million plants per annum but to avoid unnecessary costs, the multiplication of plants is based on order that is confirmed 3 to 6 months in advance (Photo 22-3). Nevertheless, excess plants from each cycle are transplanted to the nursery and sold to local buyers, particularly, sister companies involved in plantation activities. Overall, the reliable and consistent production of plantlets from the lab, complimented with the high success rate in planting-out at the nursery, has resulted in a highly efficient process for the production of clonal teak in the project (Monteuuis & Goh, 1999).

Photo 22-3 Mass production of clonal teak at the tissue culture facility of YSG Bioscape in Sabah, Malaysia

Field assessment of clones

Quality control is applied at each successive step of mass clonal teak propagation, from the introduction phase under *in vitro* conditions up to the *ex-vitro* rooting and acclimatization of the microshoots. The identification of each clone is meticulously labeled on the culture flasks and separately placed in the growth rooms to avoid mixing mistakes. To verify that the clonal plants produced from the lab were true-to-type without any abnormalities, it was necessary to conduct field trials, particularly in sites

with varying conditions. Of particular importance is the assessment between and within clone variation of the different clones with respect to growth, phenotypic features and wood properties. With these in mind, several plots comprising of both demonstrational and clonal trials were set up in Sabah between 1997 and 2002 in areas where monthly temperatures ranged at 26-28°C and annual rainfall averaged 2,500 mm without a distinct dry season (Monteuuis et al., 1998; Monteuuis, 2000; Goh et al., 2013b).

The earliest trial set up in 1997 compared trees of the eight selected Solomon clones from different vegetative propagation methods, i. e. rooted cuttings, microcuttings from nodal explants and from meristem culture (Monteuuis et al., 1998; Monteuuis 2000). The *in vitro*-issued plants regardless of their origin, developed true to type, exhibiting the same striking phenotypic features and impressive growth rate as the mother trees. Growth rates were impressive in the first few years, with annual increment of 3 to 4 m in height and 2.5-3 cm in diameter during which large leaves and very few lateral branches were produced. After 10 years, the largest-sized representatives of TG1-8 clones attained heights of about 26 m and girths of 120 cm.

In another trial set up in year 2000, the eight TG1-8 clones were tested for site suitability, that is, on a sloping piece of land and on a flatter one that was prone to occasional waterlogging (Goh & Monteuuis, 2012). An evaluation of the eight clones compared to materials from other sources showed the consistent growth of these clones with almost 100% survival and mean annual increment of 3.16 m and 2.76 m for height and 3.36 cm and 3.18 cm for DBH, respectively. Overall, indicative figures in Sabah demonstrated yields of 244 m3 /ha and 331 m3 /ha for certain clones 5 and 7 years after planting at 1250 and 1111 trees/ha, corresponding to 48.8 m3 /ha/yr and 47.3 m3 /ha/yr, respectively (Goh et al., 2013a; Goh et al., 2013b; Monteuuis & Goh, 2015). The suitability of teak growing under the conditions in Sabah was obvious from consistent results obtained from all trials and demonstration plots established to date.

At the international level, the exportation of clonal plants from YSG commenced following inquiries that came from Australia, Indonesia, Brazil, and Africa. Being the pioneer in the exportation of tissue culture teak plants to Australia, YSG had to overcome and fulfill very stringent requirements from the quarantine authorities of importing countries. The meticulous effort invested in proper documentation, coordination with freight agents and customs personnel for timely delivery, and suitable packing of bare-rooted plants in light-weighed plastic containers lined with moistened paper to ensure high survival at destination, was crucial to the creation of a workable standard operating procedure for the movement of live teak plants across the globe.

One of the earliest trial planting of clonal teak overseas was in Brazil in 2003. Prior to the introduction of the clones, planting materials in this country were entirely derived from local seeds sources. As a first step, a comparative trial between seedlings and clonal plants was set up to justify the use of clones. This demonstration plot displayed distinct differences in the growth and performance of the trees, with clonal materials outperforming seedlings by 30% in yield (Proteca, *pers comm*). Conversely, in Tanzania, the Kilombero Valley Teak Company started planting clonal plants in 2005 with the YSG Biotech TG1-8 (Goh & Monteuuis, 2012). Early results indicated the tendency of the clones to produce epicormic shoots due to the much dryer conditions. However, as in Brazil, the performance of clones was consistently much better than those of seedlings. From this outcome, KVTC has now enriched its plantations with locally selected materials in addition to the Solomon clones and has to date planted 300 ha using clonal materials out of a total of 8000 ha of teak plantations (Monteuuis & Goh, 2017). In other countries such as Australia and Indonesia, as a time-saving strategy, pilot plantations were established using the clones to verify their performance prior to large-scale planting. The outcome of these plantations once again demonstrated the consistent performance of the YSG clones as compared to local seed sources, thus leading to more confidence among potential investors in using these clones in their plantations.

Verification of clones by DNA and Wood analyses

As additional steps to confirm the quality of the clonal plants, the phenotypic selection of clones is refined through the application of wood analyses and DNA fingerprinting. Undertaken and developed by CIRAD scientists jointly with collaborators from other institutes, wood analysis through non-destructive wood core sampling and Near-Infrared Spectroscopy (NIRS) technologies is now highly possible (Goh et al., 2007; Thulasidas & Bailleres, 2017). When properly calibrated, NIRS can reveal from core samples information such as the basic density, the modulus of elasticity and strength, radial and tangential shrinkage, natural durability as well as the extractive content of the wood, all of which is highly useful for promotional and marketing of clonal materials, bearing in mind the overriding importance of wood quality for teak (Chaix et al., 2011; Kokutse et al., 2016).

Also noteworthy is the sound utilization of adapted DNA markers for overcoming issues such as genetic origin and relatedness, for establishing property rights associated with commercial transactions of the clones, for determining the primary origin of the clones, or for predicting site adaptability (genotype x site matching) (Lindgren, 2002; Graudal & Moestrup, 2017; Monteuuis, 2021). Using DNA fingerprinting to verify clonal identity is especially crucial for large-scale establishment of plantations where investment costs are high and thus, planting clonal materials with known genetics and expected growth performance will mean a more predictable yield at the end of the rotation cycle.

From the studies done, wood characteristics and DNA fingerprinting profiles for the eight YSG clones have been established and are available in the form of leaflets (Goh et al., 2007) to interested parties who are keen to consider these clones as planting materials.

Use of Teak Clones

The sucessful production and availability of clonal teak offers several attractive options to smallholders, plantation investors and even researchers in their studies. To date, several millions of YSG clones have been produced worldwide and continue to be produced to meet various demands as described in the following sub-sections.

Monospecific planting or intercropping with other commercial species

For successful large monospecific plantation establishment, in view of the injection of huge developmental funds, important factors to consider are suitable site, stringent management practices, and in particular, planting materials with good, if not, superior genetics (Photo 22-4). Rotations of more than 25 years are no longer viable or acceptable. Even revenue from the felling of thinnings in the first several years is a known welcome relief to meet cash flow needs (Ladrach, 2009; Goh & Monteuuis, 2012). With the availability of YSG clones, these are now used for establishing monospecific plantations of medium (100 to 300 ha) to large (>1000 ha) sizes depending on the availability of land and competition with other tree or crop species with the aim of getting returns in the shortest possible time frame. The yield from these large clonal plantations, being more predictable, has encouraged numerous investors to come on board in the teak business in many countries in Latin America and anticipated to be likewise in South-east Asia. For instance, two companies in Cambodia have established teak plantations using clonal plants from YSG after observing poor form and development of seedling-derived plantations. It is noteworthy that the distribution of clonal teak in the region should be more feasible than elsewhere for obvious logistic reasons, with YSG facility being geographically sited.

Photo 22-4 Monospecific teak plantation establishment using clonal planting materials with stringent and systematic management practices in Brazil (Credit: Proteca Ltda).

Good genetics are useful for establishing various agroforestry systems with the aim of achieving higher yield. Intercropping teak with other species has been practiced for a long time by smallholders in various countries. Different species can be intercropped with teak, depending on how long they are expected to produce. Annuals such as cocoa, rice, maize, beans and soybeans, or even certain short-term perennial crops like bananas and pineapples can be cultivated during the initial years between the rows of monospecific clonal plantations before the canopy closes up, depending on the initial density and clone growth rate. To date, about 20% of the total land area planted with teak are smallholder plantations (Roshetko, 2020). Regrettably, these are established with unselected and poor-quality planting stock and harvested several times from coppices (Roshetko & Perdana, 2017; Roshetko, 2020). With the availability of YSG clones, poor seed sources can now be advantageously replaced by fast-growing teak clones with long and straight clear bole, narrow crown and reduced branching. Clonal teak can also be intercropped for silvo-pastoralism (Ugalde, 2013) or with other species such as in Ivory Coast, where a pilot agroforestry plot of YSG clones with rubber was established in 2015. In Malaysia and Indonesia, owing to the competition for land use by the oil palm industries which has led to the extensive monoculture of this lucrative crop, YSG has promoted the planting of teak along the borders of oil palm plantations as seen in Sabah. The rotation of 25 years for the palm

makes it ideal for cultivating teak for a dual income harvest at the end of the cycle (Photo 22-5).

Photo 22-5 Planting of clonal teak along oil palm plantations in Sabah is encouraged for optimizing land use for a dual return that can coincide for both species at the end of the rotation cycle.

Conservation of teak clones

As far as we know, YSG Bioscape owns one of the richest and most diverse teak resources in the world. The possession of two provenance-progeny plots provides a readily available pool of potentially new planting materials in the form of clones (standing trees) or seeds (from standing trees) (Goh & Monteuuis, 2005). The two provenance cum-progeny trials were set up in 1997 in the form of partially balanced incomplete block designs in two different locations, one in a lowland with 41 seedlots (Taliwas, Lahad Datu), another in a hilly area with 42 seedlots (the Luasong Forestry Center), and with 26 seedlots being common to both sites (Monteuuis et al., 2011). These two trials were designed in such a way that the plots can be easily converted into seed production areas (Photo 22-6) for supplying genetically improved quality seeds without risks of inbreeding or from where candidate plus tree selection can be made for the production of clones adapted to a wide range of ecological conditions in tropical and sub-tropical teak-growing regions (Goh & Monteuuis, 2009). The possibility to supply superior quality clonal materials and improved seed sources from such trials will facilitate large-scale teak planting investments with more predictable and lucrative returns. It is thus crucial that genetic improvement programs with the aim of coming up with new clones arising from the establishment of clonal seed orchards be considered for long-term sustainability.

Photo 22-6 Fruits are annually collected from standing mother trees with known origins from one of the two Progeny/Provenance Plot established in 1998 in Sabah, Malaysia.

Clonal Seed Orchard establishments

Clonal seed orchards (CSOs) can be established using clones that have been selected, propagated and tested in diverse conditions. CSO-issued seeds can be used for breeding to produce seedling or timber-based populations. Jointly with CIRAD, clones from YSG have been deployed for the setting up of clonal trials in Gabon, Ivory Coast and French Guiana, for their eventual conversion to CSOs. The first of these took place in 2016, with the setting up of a clonal test comprising 32 YSG Biotech clones supplied as micro-cuttings to PFM in Gabon, Central Africa. This was followed by the establishment of 100 ha of teak clonal plantations consisting exclusively of a mixture of the same 8 YSG Biotech clones under average rainfall of 2,500 mm/yr. with a 4 month-long dry season. At about the same period, 24 YSG clones were established in a similar experimental plot in Ivory Coast. The third and most recent trial was established in early 2021 in French Guiana and comprised of 67 clones from YSG. Again, the objective is to convert at the end of the clone evaluation phase, i.e. 6 to 8 years later, into a seed orchard with these strategies in mind - i) To identify the most suitable clones and to quickly produce these clones to respond to the demand of timber in French Guiana by using criteria based on phenotypic characteristics as well as wood analyzes, and to ii) convert the plot into a CSO for the production of genetically improved seeds by considering not only the phenotypic superiority and genetic origin but also the spatial distribution of the trees in the plot (Monteuuis, 2021).

Lessons Learned and Recommendations

The vegetative propagation using tissue culture and nursery cutting techniques of clonal teak with subsequent distribution for planting has been demonstrated for their efficiency in the establishment of fast-growing and high yielding plantations (Goh & Monteuuis. 2012; Ugalde, 2013; Jerez & Coutinho, 2017). As highlighted earlier, the clonal option seems to be the best and most judicious way to maximize returns on investments in the shortest possible time using outstanding genotypes planted on suitable sites.

However, there are risks associated with the clonal option that need to be acknowledged. At the production level and likewise, when distributed to buyers, it is crucial that the identity of clones be stringently labeled to avoid potential mix-up. The personnel involved in the production must fully understand the negative implication arising from the mixture of clones or from mislabeling so that such mistakes will not happen. Owing to mixtures, some clones which are easily propagated or are more responsive will supplant those which are not, and this will result in a loss of genetic diversity. Another concern is the re-labeling of YSG clones with different names by unscrupulous companies that have managed to access these clones without permission. As a result, by promoting these clones as their own with a new set of background information, third parties may end up with the mass planting of the same clones which again, carries loss of genetic risk as highlighted. Nonetheless, as a means of mitigating these risks, the described DNA fingerprinting of clones would be an important tool for ascertaining the identity of clones in order to prevent their exploitation and is highly recommended for third parties who want to embark on mass planting of these materials.

Another common risk is the lack of adequate information regarding the genetic origin of the clones that have been mass propagated and planted, resulting in the erosion of the genetic diversity of the planting material deployed for large-scale plantings, exposing them to greater risks of pests and diseases as well as environmental impacts from climate change (Monteuuis, 2021). Although such clones contribute to the present success and financial attractiveness of teak planting, tree planters should heed their genetic diversity in order to help mitigate against the effects of climate change, the appearance of new diseases, and to allow for improvement of other qualities such as growth speed and heartwood (Graudal & Moestrup, 2017; Wanders et al., 2021). It is imperative that focus should always be given to the maintenance of a large collection of diverse sources for genetic heterogeneity and continuous improvement of the species and in turn, avoid missed opportunities in yield, adaptability or health from failure to evaluate adequately a wide range of materials (Callister, 2021).

Conclusions

The advantages of developing clonal plantations for teak have been advocated for a number of years (Monteuuis & Goh, 1999). Teak clonal plantations are expected to get the best and earliest returns on investment. This is crucial for overcoming the tremendous deficit in supply and to meet an ever-increasing international demand of superior teak wood that can no longer be harvested from natural teak forests. Intensification of crop productivity is also spurred by the increasing demographic pressure on land tenure (Monteuuis & Goh, 2018). Promising field results from cuttings or microcutting-produced clonal teak plants, and the noticeable change of mentality as far as timber plantations and land use policy are concerned, have greatly reinforced this viewpoint. As far as we are aware, YSG with the joint effort from CIRAD, has been the pioneer in operational clonal propagation and plantations of teak, and as such has an unrivalled background especially in terms of propagation experience and knowledge of field behavior of tissue culture plants.

Conversely, as seen in the early years, YSG Bioscape with a less dynamic marketing strategy, had placed more emphasis on genetic improvement of the species through the wise and prudent selection of mature Candidate Plus Trees (Goh et al., 2007; Goh & Monteuuis, 2009). These activities have been supported and well documented by numerous scientific publications and field trials that can be visited by clients who are willing to acquire YSG clones. Maintaining and producing from a broad genetic base to avoid the loss of biodiversity is part and parcel to the long-term clonal propagation of teak. After more than 20 years of activities, the company is still intensively supplying a broad variety of teak clones and genetically improved seeds from the two progeny/ provenance trials all over the world. Obviously, the type of planting materials leading to high yield and quality timber is one, if not the most pertinent factor, for consideration in large-scale plantation establishments.

The YSG clones, selected and mass-produced for widespread dissemination due to their adaptability to a diverse range of environmental conditions, have provided strong evidence that the use of clonal plants for a high value timber species such as teak is the way forward. As the supply from native teak-growing countries is no longer viable, the alternative is to produce plantation teak forests on a sustainable basis to meet increasing demands and this is now highly possible thanks to the development of techniques for the multiplication of clones at high efficiency, low costs and wide applicability as seen in the YSG project.

References

Ahuja, M. R. & Libby, W. J. (1993). *Clonal Forestry I: Genetics and Biotechnology*. Springer-Verlag, Berlin, Heidelberg, New York.

Callister, A.N. (2021). Genetic Improvement of Teak. In *The Teak Genome. Compendium of Plant Genomes* (eds. Y. Ramasamy, E, Galeano & T.T. Win), pp. 191-218. Springer, Cham. https://doi.org/10.1007/978-3-030-79311-1_13

Chaix, G., Monteuuis, O., Garcia, C., Alloysius, D., Gidiman, J., Bacilieri, R. & Goh, D. K. S. (2011). Genetic variation in major phenotypic traits among diverse genetic origins of teak (*Tectona grandis* L.f.) planted in Taliwas, Sabah East Malaysia. *Ann For Sci,* 68, 1015–1026.

Goh, D. K. S, Bacilieri, R., Chaix, G. & Monteuuis, O. (2013a). Growth variations and heritabilities of teak CSO-derived families and provenances planted in two humid tropical sites. *Tree Genet Genomes, 9*(5), 1329– 1341

Goh, D. K. S., Chaix, G., Bailleres, H. & Monteuuis, O. (2007). Mass production and quality control of teak clones for tropical plantations: the Yayasan Sabah Group and CIRAD Joint Project as a case study. *Bois et Forêts des Tropiques,* 293(3), 65-77.

Goh, D. K. S., Japarudin, Y., Alwi, A., Lapammu, M., Flori, A. & Monteuuis, O. (2013b). Growth differences and genetic parameter estimates of 15 teak (*Tectona grandis* L.f.) genotypes of various ages clonally propagated by microcuttings and planted under humid tropical conditions. *Silvae Genet,* 62, 196-206.

Goh, D. & Monteuuis, O. (2001). Production of tissue cultured teak: the plant biotechnology laboratory experience. In: *Proceedings of the Third Regional Seminar on Teak,* pp. 237-247. *31st July – 4th August 2000*, Yogjakarta, Indonesia.

Goh, D. & Monteuuis, O. (2005). Rationale for developing intensive teak clonal plantations, with special reference to Sabah. *Bois et Forêts des Tropiques,* 285(3), 5-15.

Goh, D. K. S. & Monteuuis, O. (2009). Status of the 'YSG BIOTECH' program of building teak genetic resources in Sabah. *Bois et Forêts des Tropiques,* 301, 33-49.

Goh, D. K. S. & Monteuuis, O. (2012). Behaviour of the YSG BIOTECH TG1-8 teak clones under various site conditions: first observations. *Bois et Forêts des Tropiques,* 311, 5-19.

Graudal, L. & Moestrup, S. (2017). The genetic variation in natural and planted teak forests: characterization, use and conservation for the future. In *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources*, (eds W. Kollert & M. Kleine), pp 19–29. IUFRO World Series vol 36.

Jerez-Rico, M. & Coutinho, S. (2017). Establishment and Management of planted teak forests. In: *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources*. (eds W. Kollert & M. Kleine), pp 19–29. IUFRO World Series vol 36.

Kjaer, E. D. & Foster, G. S. (1996). *The economics of tree improvement of Teak* (*Tectona grandis* L.). DANIDA Forest Seed Centre, Humlebæk, Denmark.

Kokutse, A. D., Akpene, A. D., Monteuuis, O., Akossou, A., Langbour, P., Guibal, D. et al. (2016). Selection of Plus trees for genetically improved teak varieties produced in Benin and Togo. *Bois et Forêts des Tropiques,* 328(2), 55-66.

Kollert, W. & Kleine, M. (2017). *The Global Teak Study: Analysis, Evaluation, and Future Potential of Teak Resources*. IUFRO World Series Volume 36, Vienna, Austria.

Ladrach, W. (2009). *Management of Teak Plantations for Solid Wood Products*. ISTF News, Special Report. Maryland, USA.

Lindgren, D. (2002). Advantages of clonal propagation. In: *Proceedings of the Workshop on High Quality Birch: Clonal Propagation and Wood Properties* (eds M. Welander & L. H. Zhu), pp 98–109. *27-28 August 2001*, Ronneby, Sweden.

Monteuuis, O., 2021. Clonal Teak. In *The Teak Genome. Compendium of Plant Genomes* (eds. Y. Ramasamy, E, Galeano & T.T. Win), pp. 155-169. Springer, Switzerland.

Monteuuis, O. (2000) Propagating teak by cuttings and microcuttings. In *Proceedings of the International Seminar "Site, Technology and Productivity of Teak Plantations"*, pp. 209–222. FORSPA Publication No.24/2000, TEAKNET Publication No.3

Monteuuis, O., Bon, M. C. & Goh, D. K. S. (1998). Teak propagation by in vitro culture. *Bois et Forêts des Tropiques*, 256, 43-53.

Monteuuis, O. & Goh, D. K. S. (1999). About the use of clones in teak. *Bois et Foret des Tropiques, 261*(3), 28-38.

Monteuuis, O. & Goh, D. K. S. (2015). Field growth performances of different age teak genotypes clonally produced by rooted cuttings, in vitro microcuttings and meristem culture. *Canadian Journal of Forest Research*, 45(1), 9–14.

Monteuuis, O. & Goh, D. K. S. (2017). Origin and Global Dissemination of Clonal Material in Planted Teak Forests. In *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources* (eds K. Walter & K. Michael), pp 30-38. IIUFRO World Series Volume 36, Vienna, Austria.

Monteuuis, O. & Goh, D. K. S. (2018). Teak Clonal Forestry. In: *TEAKNET Bulletin*, 11,2.

Monteuuis, O., Goh, D. K. S., Garcia, C., Alloysius, D., Gidiman, J., Bacilieri, R. &

Chaix, G. (2011). Genetic variation of growth and tree quality traits among 42 diverse genetic origins of *Tectona grandis* planted under humid tropical conditions in Sabah, East Malaysia. *Tree Genet. Genomes, 7*, 1263-1275.

Monteuuis, O.& Ugalde Arias, L. A. (2013). Chapter 3: Plant Material and Reproduction: In *TEAK: New Trends in Silviculture, Commercialization and Wood Utilization* (ed. C. R. Cartago), pp. 35-102. International Forestry and Agroforestry, ISBN 978-9968-47- 716-1.

Ramasamy, Y., Galeano, E. & Win, T. T. (2021). *The Teak Genome (Compendium of Plant Genomes)*. Springer-Verlag, Berlin, Heidelberg, New York.

Roshetko, J. (2020). "Smallholder teak systems - value addition management for livelihood enhancement in Southeast Asia". TEAKNET Webinar series 4, ICRAF, Indonesia on 15 September 2020.

Roshetko, J. & Perdana, A. (2017). The significance of planted teak for smallholder farmers. In *The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources* (eds K. Walter, K. Michael K), pp 66–70. IIUFRO World Series Volume 36, Vienna, Austria.

Thulasidas, P. K. & Baillères, H. (2017). Wood quality for advanced uses of teak from natural and planted forests. In The Global Teak Study: Analysis, Evaluation and Future Potential of Teak Resources." (eds. W. Kollert & M. Kleine), pp. 78–81. IIUFRO World Series Volume 36, Vienna, Austria.

Ugalde, A. L. A. (2013). *Teak: new trends in silviculture, commercialization and wood utilization* (No. 634.97388/U26). International Forestry and Agroforestry. 552 p.

Wanders, T. H. V., Ofori, J. N., Amoako, A., Postuma, M., Wagemaker, C. A. M., Veenendaal, E. M. & Vergeer, P. (2021). Teak genetic diversity in Ghana shows a narrow base for further breeding and a need for improved international collaboration for provenance exchange. *Genetic Resources, 2*(4), 44–54.

Zobel, B. & Talbert, J. (1984). *Applied Forest Tree Improvement*. Wiley, New York.

SECTION VI:

POLICY AND REGIONAL / INTERNATIONAL COLLABORATION

Chapter 23: Ensuring Legal and Sustainable Teak Supply Chains in the Lower Mekong Region

Ma Hwan-ok

Abstract

Timber legality has become a critical component of international timber trade in the largest consumer markets of Europe, the US, and Japan for sustainably produced forest products from legal sources in order to address the rampant illegal trade in forest products across international borders. This trend has been reflected in the recent timber trade regulations, including the US Lacey Act (2008), EUTR (2010), Australian Illegal Logging Prohibition Act (2012) and Japan Clean Wood Act (2017) that aim at prohibiting the import of timber products harvested or traded in violation of applicable national or foreign laws. This has placed pressure on the governments of the timber producing countries to introduce regulatory compliance systems in line with the global timber market requirements in particular to facilitate market access. The teak producing countries in the Mekong region have also responded to this growing requirement and are working to evolve nationally suitable timber legality assurance systems in partnership with the EU Voluntary Partnership Agreement, in line with their timber certification experiences. Effective implementation of teak timber legality and sustainability is both a big challenge and a good opportunity for the teak growing countries of the region. Intense efforts to design and implement effective timber legality assurance systems with a set of standard criteria and indicators are critical to advance the economic, environmental and social benefits from the teak-based forest resources of the Mekong region (ITTO, 2016).

Introduction

The concept of supply chain comprises the organizations, activities and processes associated with all stages of the business involving planning, sourcing, manufacturing and delivering goods and services. Recognizing the importance of increasing efforts to prevent forest degradation and contributing to the global effort of addressing climate change, the 55th session of the International Tropical Timber Council in December 2019 adopted the ITTO's new programme on Legal and Sustainable Supply Chains (LSSC). This programme, in collaboration with partners, is aimed at ensuring all flows into the tropical timber supply chains from forests to markets and onwards to the final consumer are legally and sustainably sourced and traceable to their origins in a credible and cost-effective manner.

An international forum on global green supply chains was held in Shanghai in 2019 under the LSSC programme by the ITTO in collaboration with several partners including the China Timber & Wood Products Distribution Association (CTWPDA) with generous financial support by the Federal Ministry of Food and Agriculture of Germany. At the forum all participants agreed on the urgency to create a "green supply-chain mechanism" to promote a stable, legal and sustainable supply of tropical timber and wood products, bringing together all stakeholders.

Legal and sustainable timber supply chains ensure best practices of management including sustainable timber harvesting, lawful sourcing, and transparency at each stage of the supply chains from harvesting to domestic and international markets. Traceability and accountability in the supply chains are critically important to ensure transparency, reliability, compliance and responsibility in the advancement of sustainable management of forest resources. Timber tracking systems are able to link timber with its source, showing the proof of origin. Therefore, companies can show they are fulfilling the implementation of timber legality by using tracking systems. For governments, implementing timber and timber product tracking systems leads to improvement in the performance of their forest sector governance by reducing illegal logging and theft of valuable national asset besides benefitting the environment and people (ITTO, 2021).

Sustainable Forest Management

Promoting legal and sustainable supply chains is an important initial step in the development and implementation of sustainable forest management (SFM) policy and regulations. To assist in monitoring and assessing the condition of natural tropical forests, ITTO pioneered the development of criteria and indicators (C&I) for SFM in the early 1990s. This C&I framework has served as a model for developing national indicators to assess the progress of implementing SFM. The ITTO C&I for the sustainable management of tropical forests comprise seven criteria, 18 indicator groups that subdivide the criteria, and 58 indicators. The Box below illustrates the 7 criteria, considering the SFM objectives.

Box 23-1 The SFM objective for managing natural tropical forests and their relationship to seven principles and criteria.

SFM objective	Principle	Criterion
1. Providing the enabling conditions for SFM	Principle 1: Forest governance and security of tenure Principle 2: Land-use planning, permanent forest estate and forest management planning	Criterion 1: Enabling conditions for SFM Criterion 2: Extent and condition of forests
2. Ensuring forest ecosystem health and vitality	Principle 3: Ecological resilience, ecosystem health and climate change adaptation	Criterion 3: Forest ecosystem health and resilience
3. Maintaining the multiple functions of forests to deliver products and environmental services	Principle 4: Multipurpose forest management Principle 5: Silviculture management	Criterion 4: Forest production Criterion 5: Forest biodiversity Criterion 6: Soil and water protection
4. Integrating social, cultural and economic aspects to implement SFM	Principle 6: Social values, community involvement and forest-worker safety and health Principle 7: Investment in natural forest management and economic instruments	Criterion 7: Economic, social and cultural aspects

Source: ITTO (2015)

This is a flexible and robust framework for addressing emerging forest-related issues at the international and national level. It recognizes the implication for SFM of legally and non-legally binding international agreements at the regional and global levels. For example, the role of forests in promoting sustainable production and consumption in addition to contributing to climate change and conservation and sustainable use of biodiversity is a novel challenge for SFM. The Criterion 1 highlights enabling conditions for SFM to ensure forest governance as well as land-use planning and forest management planning. Well-planned and sustainably managed production forests addressing both legality and sustainability will facilitate the sustainable production of a range of forest goods and ecosystem services towards development of forest-based bioeconomy. Adjusting the national legal and regulatory frameworks to incorporate the appropriate provisions of legal and sustainable supply chains is essential to the continued improvement of SFM in tropical countries.

Timber Certification Systems

Globally there are two major organizations that provide forest certifications: The Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). Both of these organizations have set international benchmarks by which regional and national standards are accorded endorsement. The FSC was started in 1993 through collaborative efforts by a number of European environmental groups and its Principles and Criteria (P&C) have evolved greatly over the past three decades. Version 5 of these P&C with 10 principles and 70 criteria is currently in use. Indicators and Verifiers, adapted to each national context and consolidated in National Forest Management Standards, are used by Certifiers to ensure compliance with P&C.

The PEFC was established in 1999 by a number of stakeholders including environmental organizations and private companies in North America. The PEFC sustainability benchmarks include 7 criteria. All regional and national forest certification systems are required to undergo third-party assessment against PEFC's sustainability benchmarks before they can achieve endorsement. In the case of acceptance of plantations, the FSC has set 1994 as deadline of plantation development so that plantations developed after 1994 are not accepted while there is no specific deadline for plantation development in the PEFC (2022).

FSC's 10 Principles and PEFC's 7 Criteria are presented in Box 23-2.

Box 23-2 FSC's 10 principles and PEFC's 7 criteria

	The Forest Stewardship Council (FSC)	**Programme for the Endorsement of Forest Certification (PEFC)**
Principle / Criterion	10 Principles	7 Criteria
	1: Compliance with Laws	1: Maintenance or appropriate enhancement of forest resources and their contribution to the global carbon cycle
	2: Workers Rights and Employment Conditions	2: Maintenance of Forest Ecosystem Health and Vitality
	3: Indigenous Peoples' Rights	3: Maintenance and Encouragement of Productive Functions of Forests
	4: Community Relations	
	5: Benefits from the Forest	

	The Forest Stewardship Council (FSC)	Programme for the Endorsement of Forest Certification (PEFC)
	6: Environmental Values and Impacts 7: Management Planning 8: Monitoring and Assessment 9: High Conservation Values 10: Implementation of Management Activities	4: Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems 5: Maintenance or appropriate enhancement of protective functions in forest management 6: Maintenance or appropriate enhancement of socio-economic functions and conditions 7: Compliance requirements - Legal Compliance - Legal, customary and traditional rights related to the forest land - Fundamental ILO conventions - Health, safety and working conditions
Forest management certification	238 million ha (as of February 2022)	330 million ha (as of February 2022); About 58% of all certified forests globally are certified to PEFC
Chain of Custody (CoC)	51,101 certificates (as of February 2022)	20,000 certificates (as of February 2020)

Source: www.fsc.org and pefc.org, accessed February 2022

FSC Principle 1 (Compliance with Laws) specifies the legal aspect of forest management certification. Any applicants shall comply with all applicable laws, regulations and nationally-ratified international treaties, conventions and agreements. PEFC requires that property rights, tree ownership and land tenure arrangements shall be clearly defined, documented and established for the relevant management unit.

In addition to legal compliance, both certification systems cover a broad range of environmental and social issues. These include ensuring sustainable harvest levels and regeneration after harvest; maintaining high conservation values to protect biodiversity; conservation of soils and water quality; social considerations for local communities and forest worker's rights; monitoring the environmental and social impacts of the forest management. The principles are accompanied by a number of criteria and corresponding indicators to enable practical implementation.

The objective of forest management certification is to ensure the forests are managed according to laid down standards which is checked through a third-party certification while the chain of custody (CoC) certification aims to guarantee the traceability of raw material from the forest to the end product.

In the lower Mekong region, the extent of area certified and number of chain-of-custody certificates are the highest in Vietnam followed by Thailand, Lao PDR and Cambodia while Myanmar has just began opting for certification (Table 23-1). The primary reason for the outstanding performance of Vietnam in certification is the export-oriented nature of its timber industry and the long-term presence of FSC in the country.

Table 23-1 Area certified and number of chain-of-custody certificates issued by the Forest Stewardship Council and the Programme for the Endorsement of Forest Certification in Lower Mekong Region

Country	Total Forest Area (1,000 ha)	Forest Stewardship Council		Programme for the Endorsement of Forest Certification		Total	
		Area certified (ha)	No of Chain-of-custody certificates	Area certified (ha)	No of Chain-of-custody certificates	Area certified (ha)	No of Chain-of-custody certificates
Cambodia	8,068	7,896	36	-	-	7,896	36
Lao PDR	16,596	78,891	2	-	-	78,891	2
Myanmar	28,544	-	17	-	1	-	18
Thailand	19,873	121,814	260	-	27	121,814	287
Vietnam	14,643	227,523	1,076	46,657	30	274,180	1,106

Sources: Global Forest Resources Assessment 2020; www.fsc.org and pefc.org, accessed February 2022

Forest certification is a broadly accepted way to demonstrate SFM at forest management unit level towards better management of forest resources. Increasing certified areas is a good indicator for best practices and investing in the continuous improvement of forest management.

Certification processes presents many advantages: increased transparency, accountability and control of forest production; contribute to the improvement of the forest management system, with good practices of operational control and safety and health requirements at work. It also contributes importantly towards creating a good public image for the company for practicing sustainable forestry besides strengthening partnerships between companies, suppliers and customers.

However, tropical forests as a whole are still lagging behind in forest certification. The most difficult thing is to finance additional costs - indirect (compliance) and direct (auditing) costs of certification requiring substantial transaction costs including training of local auditors. Complexity of standards for community forests and smallholders continue to be at disadvantages in accessing and implementing forest certification. Currently, meeting legality regulations is the primary reason for seeking SFM certification.

Timber Legality Assurance Systems

Timber legality has become an essential component of international timber trade. The global timber markets have become increasingly sensitive to timber sourced unsustainably, with consumer markets demanding forest products from legal sources. This puts pressure on the producer countries to adopt higher levels of sustainability in forest management approaches thus reducing illegal trade in forest products (ITTO, 2019).

Country governments in many of these countries are introducing regulatory compliance systems that influence market access. In many cases, where the countries' domestic regulations do not require certification, companies are themselves applying for voluntary forest certification system to demonstrate sustainability to their potential consumers (Martin & Ghazali, 2015).

The EU has conducted an extensive and broad-based outreach effort through voluntary partnership agreements (VPAs) within the context of its 'Forest Law Enforcement (FAO & ITTO, 2010), Governance and Trade

(FLEGT)' initiative. The aim of FLEGT VPAs is to facilitate trade in legal timber through capacity building and civil-society involvement for FLEGT licences for timber exports to the EU, and the EU has been engaging in negotiations on VPAs with many tropical timber-producing countries (EU FLEGT Facility, 2019). The EU considers timber accompanied by a FLEGT export licence as meeting the legality requirements described in the EU Timber Regulation. Central to the success of the FLEGT timber export licensing system is a transparent system in the timber-producing country to verify the compliance of timber exports with the applicable national laws. This system of verification or validation of legal compliance is referred to broadly as a timber legality assurance system (TLAS) though the specific nomenclature varies from country to country.

The VPA legality definition itself sets out the core requirements of legislation applicable to timber in a country in the form of principles, criteria and verifiers. All elements of the legality definition need to be complied with in order for the timber to be considered to have been legally produced. In general, a timber legality definition covers the following principles: (i) legal rights to harvest and recognition to other parties' legal tenure rights, (ii) compliance with relevant national legislation as it pertains to forest management, environment, labour and health & safety, and (iii) payment of due taxes, fees, duties, royalties and penalties.

However, timber legality is complicated in many tropical countries as in some countries, laws may be unclear or conflicting making it difficult to clearly define "harvested in accordance with the applicable legislation in the country of harvest". In such difficult cases of defining timber legality definition, it would also be important to assist the development of a practical working definition of 'legal' or a set of applicable laws.

To assure timber legality, the Government of Vietnam has signed a Voluntary Partnership Agreement (VPA) with the EU to implement FLEGT while Cambodia, Lao PDR, Myanmar and Thailand are in the process of either initiating or finalizing their negotiation with the EU (ITTO, 2018).

Box 23-3. summarizes the status of negotiations and key element of timber legality definition

Box 23-3. Status of voluntary partnership agreement and key elements of timber legality definition in the Lower Mekong Region

Country	Voluntary Partnership Agreement (VPA) timeline	Key Elements of Timber Legality Definition
Cambodia	FLEGT Work Plan adopted in 2021 with four target interventions including developing a Cambodian Timber Legality Definition, capacity building and testing model areas of timber trading originating from community forestry and plantations	Legal rights to harvest are specified in the forestry law 2002. All forest products and by-products (timber products, non-timber forest products and processed products) located and originating from the permanent forest reserve are state property. Any individual, legal entity or community intending to harvest forest products and by products for commercial purposes must possesses documents in accordance with the forest law 2002

Country	**Voluntary Partnership Agreement (VPA) timeline**	**Key Elements of Timber Legality Definition**
Lao PDR	The official VPA preparation and negotiation with EU started in 2016 and it is still in the negotiation stage. Once FLEGT-VPA is agreed, timber and timber products complying relevant regulations will receive FLEGT licenses.	1: Production Forest Areas (which currently include 18 legal references); 2: Conversion areas (based on 19 legal references); 3: Timber plantations: (based on 16 legal references); 4: Village use forests (not yet drafted, as villagers cannot legally log and sell timber); 5: Confiscated timber: (based on 19 legal references); 6: Imported timber: (based on 3 legal references); 7: Labour obligations in forestry, wood processing and trading operations (based on 9 legal references); 8: Wood processing and trade: (based on 19 legal references)
Myanmar	Started to engage with FLEGT in 2015. In November 2018, the national Multi-Stakeholder Group was formally established to represent the interests of all forest sector stakeholders in guiding future activities related to FLEGT in Myanmar.	A. Legal in Harvesting: Receipt of logs at private log yard, Permit to process timber, Outturn percentage approval, Certificate of legality of timber products B-C. Legal in Transportation and in Product Processing: Specification, Sale Contract, Commercial Invoice, Delivery Order, Advanced Information for Parcel Transfer, Reference for Parcel Transfer, Purchase Confirmation Letter and Certified Letter for Source of Origin D. Legal in Trade/ Marketing: Export License, Export Declaration
Thailand	VPA is expected to be signed in 2023. The Fourth Thailand-EU FLEGT VPA Negotiation is scheduled to take place in 2022 to review all requirements.	Principle 1: Operator Legality (including Land) Principle 2: Forest Management and Harvesting Timber Principle 3: Sourcing and Transportation of Timber/Timber product/Reclaimed wood Principle 4: Environment and Social Management Principle 5: Welfare and Labour Protection Principle 6: Tax, Fee & Other Payment
Vietnam	Signed VPA with the EU in June 2019. This legally binding agreement aims to improve forest	Principle I: Harvesting of domestic timber complies with regulations on land use rights, forest use rights, management, environment and society.

Country	Voluntary Partnership Agreement (VPA) timeline	Key Elements of Timber Legality Definition
	governance and promote legal timber trade between Vietnam and the EU.	Principle II: Compliance with regulations on handling confiscated timber. Principle III: Compliance with regulations on importing timber. Principle IV: Compliance with regulations on timber transportation and trade. Principle V: Compliance with regulations on timber processing. Principle VI: Compliance with regulations on customs procedures for export. Principle VII: Compliance with regulations on tax and employees.

Source: https://www.euflegt.efi.int/vpa accessed February 2022 and ITTO MIS reports

In Vietnam, several follow-up steps for VPA/FLEGT implementation are taking place. On December 29, 2021, the Ministry of Agriculture and Rural Development of Vietnam issued a Circular to specify the classification of wood processing and export enterprises based on the principle of ensuring publicity, transparency, competence, order and procedures of the government's regulations. According to the ITTO TTM Report (26:4 1 - 28 Feb 2022), importers need to submit additional documents to prove the legality of imported wood when they import wood from risk sources under Vietnam's Timber Legality Assurance System (VNTLAS) highlighting Vietnam's commitment to the EU to avoid illegally sourced wood from the supply chain and the Vietnam - US Agreement to improve wood legality.

International Timber Trade Policy and Regulations

Over the past decade the international timber trade increasingly requires the producer countries to adopt higher levels of sustainability in forest management approaches, reducing illegal trade in forest products. In the context of international timber trade regulations important policies and regulations that seek to address illegal logging and associated trade include the US Lacey Act (2008), EUTR (2010), Australian Illegal Logging Prohibition Act (2012) and Japan's Clean Wood Act (2017). All these regulations set out that all actors in the timber supply chain are responsible for ensuring the legality of the timber they purchase and must declare the identification and country of origin of the timber traded. The US Lacey Act requires the declaration of scientific name (genus and species), whereas the remainder only require trade names, common names, or genus where the full scientific name is unknown. The Lacey Act and Clean Wood Act require only that the country of origin be declared for traded timber, whereas EUTR requires the region and concession of harvest "where applicable", and Australia requires region and harvesting unit information in all cases. Box 4 provides a summary of international timber trade regulations.

In addition to these declaration requirements, EUTR, Australia Act and Japan Clean Wood Act require importers to fulfill requirements for due diligence and provide evidence that the timber has not been illegally sourced. Legislation designed to address demand-side factors is in addition to laws governing the regulation of trade in endangered species, as is required by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Box 23-4 A summary of international timber trade regulations

	United States- LACEY ACT	**European Union- EUTR**	**Australia- ILLEGAL LOGGING PROHIBITION ACT**	**Japan- CLEAN WOOD ACT**
Regulated products	Any wild part of the plant, including roots, seeds, and products thereof	Timber product prescribed in the annex to the EU TR (2010)	Raw logs and sawn timber, paper, pulp and furniture (prescribed in Schedule 1 of the amendment reg. 2013)	Logs, sawn boards and square timber, veneer; plywood, laminated veneer lumber and laminated wood, and wood pellets, woodchips and wood particles
Legal provisions on illegal timber	It is unlawful to import, export, sell, acquire, or purchase any plant that are taken, possessed, transported, or sold in violation of US, or in interstate or foreign commerce involving any plant taken possessed or sold in violation of State or foreign law	Obligations of operators prohibiting the placing on the market of illegally harvested timber or timber products derived from such timber	An importer must, before importing a regulated timber product, obtain the information about the product if a timber legality framework applies to the timber in the product, or the area in which the timber is harvested—a copy of the license or certificate issued to the harvester of the timber, that provides evidence of compliance	All timber-related entities to ensure that the timber and timber products they handle are legal
Timber Species identificati on	Scientific name of any species used	Trade name and type of product, common name and scientific name of tree species	Common name, genus or scientific name of the tree	Types of the wood
Timber species origin	Country of origin	country of harvest and where applicable to indicate sub-national region where the timber was harvested and concession of harvest	The name of the country, the region of the country and the forest harvesting unit	The names of the countries or regions where the trees used as raw materials were harvested.

Source: adopted from ITTO's Legal and Sustainable Supply Chains (LSSC) learning course (ITTO, 2021)

The Way Forward

International timber trade in large consumer markets such as Europe, the US, and Japan is moving with challenges and opportunities to prove the legality and sustainability of timber products to access markets. For sustainable production and sustainable trade of teak timber products, teak production forests in the tropics should be managed efficiently and effectively with the demonstration of legality and sustainability.

Since the demonstration of legality and sustainability is a major challenge for the tropical timber sector, capacity building of tropical timber producing countries should be supported to address a serious lack of capacity to cope with timber legality and sustainability requirements. In the case of sustainability assessment, international, regional and national criteria and indicator initiatives have been established although the implementation has been varied. However, the implementation of timber legality definition will require a lot of additional efforts with practical guidelines for wider implementation in a cost-effective way. More partnerships among stakeholders are essential to promote a legal and sustainable trade of tropical timber and enhance the trade's positive impact on legal compliance and SFM.

As the counties in the lower Mekong move into the development of timber legality definition or the implementation phase of a timer legality system, it is critical that the private sector, including teak farmers, smallholders, small and medium size enterprises (SMEs) to improve SFM documentation through digitalization to account for the changing international timber trade policies and regulations. Responsible and transparent documentation to verify legality and sustainability is a key issue that must be addressed in the context of enhancing SFM and the general public's perception of tropical timber harvesting.

The government authorities should play a key role in developing an electronic wood tracking system which allows applicants to register, renew and extend contracts online to track wood from the point of harvest to the point of sale in order to ensure transparency and to be able to verify the origin of wood products. Research is needed for the application of blockchain technology in the tropical timber tracking system with a view to improving the legality and sustainability in the global supply chains of international timber production, processing trade and consumption.

Lessons from the implementation of timber tracking pilot platforms need to be shared across the countries of the lower Mekong region and intensely debated not only to promote legality verification but also to establish a brand of teak products based on their origin and management stories to add values.

Sustainably managed teak forests and sustainable trade of legally produced teak wood products are contributing to the achievements of many targets of the Sustainable Development Goals. Harnessing the achievement of legal and sustainable supply chains should be facilitated through research and capacity building for technical expertise, enabling policies and stable legislation, transparency and governance, and cost-effective independent legality verification and voluntary SFM certification.

Reference

EU FLEGT Facility. (2019). *Small and micro-size entities in the Mekong region's forest sector: a situational analysis in the FLEGT context*. http://www.euflegt.efi.int/publications/small-and-micro-sized-entities-in-the-mekong-region-s-forest-sector

FAO & ITTO. (2010). *Forest law compliance and governance in tropical countries*. http://www.fao.org/3/al044e/al044e00.pdf
FSC (The Forest Stewardship Council). (2022). *Facts and Figures*. https://fsc.org/en/facts-figures

ITTO (International Tropical Timber Organization). (2015). *Voluntary guidelines for the sustainable management of natural tropical forests*. ITTO Policy Development Series No. 20. International Tropical Timber Organization, Yokohama, Japan.

ITTO (International Tropical Timber Organization). (2016). *Criteria and indicators for the sustainable management of tropical forests*. ITTO Policy Development Series No. 21. International Tropical Timber Organization, Yokohama, Japan.

ITTO (International Tropical Timber Organization). (2018). *FLEGT VPA Partners in EU Timber Trade 2018*. ITTO/FLEGT Independent Market Monitor (IMM). https://www.flegtimm.eu/images/IMM_2018_Annual_Report/Final_clean_version_Natalie_VPA-Partners-in-EU-Timber-Trade-Annual-Report-2018.pdf

ITTO (International Tropical Timber Organization). (2019). *Trade and Market Transparency Programme*. https://itto-d2.r-cms.jp/files/user/pdf/ITTO_CaseForSupport_TMT_brochure.pdf

ITTO (International Tropical Timber Organization). (2021). *Legal and Sustainable Supply Chains (LSSC) learning course*. https://www.itto.int/news/2021/06/23/itto_launches_e_course_on_legal_sustainable_timber_supply_chains/
ITTO (International Tropical Timber Organization). (2022). *Tropical Timber Market Report*. (26:4 1 - 28 Feb 2022)
Martin, R. M. & Ghazali, B. H. (2015). *The impact of timber procurement policies: an analysis of the economic effects of governmental procurement policies in tropical timber markets*. ITTO Technical Series No. 44. International Tropical Timber Organization, Yokohama, Japan.

PEFC (The Programme for the Endorsement of Forest Certification) (2022). *PEFC Global Statistics Data December 2021*. https://cdn.pefc.org/pefc.org/media/2022-03/b33a1b64-6d71-4dd1-a3dc-ede164221d2a/eaba7ece-0afd-56fa-bce9-b5ab265c95a4.pdf

Chapter 24: Forests, Timber Sources and Supply Chains of Myanmar: Opportunities and Constraints to Ensure Legal Origin of Timber

Taiji Fujisaki and Barber Cho

Abstract

Since the late 2000s, the global timber trade has undergone emerging legality requirements on imported timber products in major consumer countries. For Myanmar, as a key country in supplying tropical hardwood, the potential to participate in expanding regulated markets rests on its capacity to hold accountability for the legal origin of timber products, which requires greater transparency of the supply chain, traceability of products, and supportive proof of legal claims.

Against this backdrop, this study was undertaken to enhance the production and trade of legally harvested timber in Myanmar by examining legal frameworks and measures and identifying challenges ahead. Based on the desk review research, the study discussed forest classification, timber sources (e.g., selective logging, forest conversion, plantation, etc.), and supply chains and examined log marking and paper-based systems to track the legal origin.

The study identified that the current systems help trace logs from log yards of private industries to a township of harvest. In addition, to increase transparency, the government has published production data from main timber sources and opened relevant supply chain documents to the public. Such efforts can promote legal timber production and trade, delivering positive signals to concerned actors. On the other hand, the absence of production data from Natural Forest conversion may undermine the overall efforts of the forestry sector in Myanmar. In addition, the accountability of the legal origin of timber products needs to consider not only locations where timber was harvested but also focus on the types of timber source and forest since each source and/or forest type may associate with particular risks, considerations, and implications for a legal basis.

Introduction

Myanmar holds a vast expanse of tropical natural forests and plays a vital role in supplying tropical hardwood, including Teak (*Tectona grandis*), a globally traded high-value timber species. Natural teak forests are estimated to cover 29 million ha globally, of which nearly half are found in Myanmar (Kollert & Kleine, 2017). However, the past economic-oriented forestry sector has led to the over-exploitation of forest resources resulting in the degradation of natural forests in Myanmar. Furthermore, several studies revealed illegal and unsustainable logging and illegal border trade (Springate-Baginski et al., 2016), and conflicts over land rights, especially with customary landowners (Oo et al., 2021). Consequently, the forestry sector in Myanmar has presented challenges in achieving legal timber supplies, and may have difficulty in finding a market in the globally expanding timber legality regime (Forest Trends, 2021).

The crucial question is what we have to consider to enhance the country's capacity that ensures and demonstrates the legal origin of timber. To promote legal timber production and trade, the forestry sector in Myanmar has undergone substantial reforms in the past decade. These include the revision of the Forest Law in 2018 and related regulations, increased reserved areas for forest management, reduced exploitation of natural forests, a ban on exporting logs and products using timber derived from unsustainable sources, the establishment of plantation resources, and the greater inclusion of local communities and the private sector in forest management (Forest Department, 2020; World Bank, 2020). In addition, the Ministry of Natural Resources and Environmental Conservation (MONREC) published a report entitled the Chain of Custody Dossier (the CoC Dossier) in 2018 to address the transparency in the timber supply chain in Myanmar, which explains detailed steps in producing legal timber from state-managed natural forests.

On the other hand, understanding and ensuring the legal origin of timber is not straightforward, given complex legal frameworks over forests, timber production, and supply chains. Often a country has multiple sources for timber production with different standards and procedures. Moreover, in most tropical countries, the supply chain control is not well established and implemented effectively (Banikoi et al., 2019), which makes it challenging to ensure and demonstrate the legality of timber products.

There have been several studies on timber production and supply chains in Myanmar, such as those of Woods (2013), Springate-Baginski et al. (2016), Banikoi et al. (2019), Rand et al. (2019), Forest Trends (2021), and (World Bank, 2019, 2020). However, there is still a need to elaborate a comprehensive picture, including forest classification, timber sources, and consequent timber flows, to discuss opportunities and constraints for Myanmar with an aim to enhance legal timber supply and trade.

Against this backdrop, this study was conducted under the ITTO project "*Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region*" to enhance the production and trade of legally harvested timber in Myanmar by examining legal frameworks and measures concerning the issues related to the timber legality and identifying challenges ahead. Two broad questions were posed to guide the analysis:

- Where timber can be harvested, by whom, and how is it produced, distributed, and traded?
- What measures are taken, and to what extent have they been effective to demonstrate the legal origin of harvest?

This chapter is organized as follows: Section 2 below describes the methodology adopted for the analysis. Section 3 provides an overview of the timber legality regime, which is taking place at a global level, and then explores the critical considerations for the timber legality that guides the analysis. Focusing on timber productions, Section 4 discusses the forest land classification in Myanmar and its legality implications. Section 5 identifies timber sources and supply chains. Section 6 identifies current mechanisms and measures to demonstrate the origin of harvest and challenges. Finally, Section 7 elaborates on the findings and concludes with some considerations.

Methodology

The study was conducted based on the desk review research using the publicly available information and data provided by the Myanmar government. Our review includes the Land Use Policy (2016), the Forest Law (2018), the Forest Rules (2019), the Vacant, Fallow and Virgin (VFV) Land Management Law (2012, amended in 2018), and the Community Forestry Instructions (2019), as well as the government's reports on the forestry sector, and statistical data on timber productions. In addition, the study was developed through discussions with professional members of the Myanmar Forest Certification Committee (MFCC) and email-based questionnaires survey to experts on Myanmar's timber sector.

On the other hand, the study has limitations. First, due to the impact of the COVID-19 pandemic, the field survey was impossible to conduct. Therefore, our findings and conclusion are drawn on publicly available information and data without field observations. Second, the study focuses on a technical aspect of institutional design and measures to discuss legal timber production and trade in Myanmar. It is not our intention to glance at the current unrest situations in Myanmar and explore their implications for the forestry sector and timber legality.

Key Consideration for the Timber Legality: Emerging legality requirements in major consumer countries

Since the late 2000s, the global timber trade has undergone emerging legality requirements on imported timber products in major consumer countries. Import restriction of illegally harvested timber products was first introduced in the USA by the Amended Lacey Act (2008), followed by Australia's Illegal Logging Prohibition Act (effective in 2012) and the EU Timber Regulation (effective in 2013). In Asia, Japan enacted the Clean Wood Act in 2017 to encourage importing legally harvested timber products, and the Republic of Korea introduced the legislation banning the import of illegally harvested timber in 2018. Also, Indonesia and Viet Nam have regulated their timber imports along with the voluntary partnership agreement with the EU. As a result, timber imports into those regulated markets account for more than half of global trade in 2019. In addition, China, the largest timber importer, amended its Forest Law in 2019 and prohibited using illegally sourced timber[1]. Consequently, the share of regulated timber markets is expected to increase.

It is important to note that legality/illegality of timber is a broad term that encompasses not just harvesting but also transportation, processing, and trade(Smith, 2002), and there is no globally agreed single set of rules and criteria for timber legality. Hence, the standards and procedures required to import products into the countries mentioned above vary. However, the critical focus commonly found is accountability for the legal origin of timber products they have sourced (Bartley, 2014). Consequently, there is growing attention to map the timber supply chains to identify and demonstrate the legal origin of timber products and avoid unknown or illegal sourced timber products. This requires timber producer countries to improve the transparency of the supply chain, traceability of products, and supportive proof of legal claims, in addition to the traditional perspectives of quality, price, and stable supply in the timber trade.

The crucial question is what we have to consider to understand the country's capacity, which ensures and demonstrates the legal origin of timber. Firstly, timber harvest needs to take place from forest areas with a specified legal basis (Springate-Baginski et al., 2016). However, in several tropical countries, competing interests and practices over forested areas, such as agriculture, forestry, infrastructure development, customary uses, small-scale farming, and biodiversity conservation, have been observed, which cause numerous conflicts and insecurity in the legality of activities. Accordingly, the design, demarcation, and maintenance of forests to be distinct from other land use, especially agriculture, are essential in building the legal origin of harvest (Fay & Michon, 2003). Brown et al. (2008) further discuss legal origin as the legal right to harvest, including prior determination and settlement of tenurial claims over a given forest. These discussions highlight that in an attempt to ensure the legal basis of timber products, the forest classification and gazettement have to include procedures to determine harvest areas, considering different land use objectives, interests and claims. Such deliberation is highly relevant to Myanmar's context, given several reports concerning land conflicts with local communities (World Bank, 2019, 2020; Oo et al., 2021).

Another critical element to account for is the traceability and transparency of the

[1]As of writing, implementing regulations of the amended law have not yet been issued.

timber supply chain. Generally, a country has multiple forms to harvest logs, namely legal timber sources, rather than a single form. Then timber is distributed and processed through complicated supply chains, including different governance mechanisms and actors (Banikoi et al., 2019). Accordingly, a system to inform concerned actors about where a product comes from is the first step to demonstrate the legal origin of timber products while avoiding unknown-sourced timber. In order to build such capacity, traceability studies discuss different measures, such as track & trace, segregation, and mass balance. Table 1 highlights how each measure can support traceability to ensure the legal origin of timber products.

Table 24-1 Measures supporting traceability of legal origin of timber products

Measures	Function
Track and trace	Include both physical marking and information management methods. A batch of products can be directly traced to its origin, such as the forest compartment where the log was harvested.
Segregation	A batch of timber is kept, traded, processed and distributed separately by source according to the objectives.
Mass balance	Also known as inventory management methods. The volume of timber products is monitored partly or throughout the entire supply chain so that it can be checked whether there are no discrepancies.

Source: Seidel (2011), Mol & Oosterveer (2015) and Arts et al. (2021)

It is critical to consider what supply chain information is generated and communicated along the supply chain so that these measures can be functional(Arts et al., 2021). At the same time, it questions what information is being made transparent and who is entitled to access such information. In this regard, transparency is seen as a prominent subject in demonstrating the legal origin of timber products and making claims reliable.

Forest Classification and Timber Harvest

Permanent forest estate

Administratively, the land in Myanmar is broadly classified into three categories, which are agricultural land, forest land, and other land. The Ministry of Agriculture and Irrigation (MOALI) administrates the agricultural land, while the Forest Department (FD), a division of MONREC, is responsible for the forest land and trees on the agricultural land. Forest land is referred to as Permanent Forest Estate (PFE), which is constituted of Reserved Forest and Protected Public Forest.

Reserved Forest is set in areas suitable for commercial timber production with higher commercial value, where the public has no harvesting rights. On the other hand, Protected Public Forest is designed mainly for conservation and local use, while commercial timber can also be sourced. In addition, MONREC designates Protected Areas to preserve diverse ecosystems and species richness of Myanmar and cannot be exploited. Table 2 shows the extension of those designated areas as of December 2019

Table 24-2 Permanent Forest Estate and Protected Areas in Myanmar (December 2019)

Legal classification	Area	
	ha	% of land area
Reserved Forest	12,020,011.79	17.77%
Protected Public Forest	5,224,273.51	7.72%
Protected Areas (PAs)	3,959,316.61	5.85%

Source: Forest Department (2020)

Unclassified forests

It is important to note that "the PFE or Forest Land," legally designated forest land, does not necessarily mean ecological forest (areas dominated by trees). Indeed, large forested areas expand outside the PEF. For example, the REDD+ Programme Myanmar(no date)estimates that 6,916,470 ha of closed forest and 10,331,664 ha of open forest[2] lie outside the PFE. Those forests are referred to as "Forest Covered Land at the disposal of the Government" in the Forest Law (2018) but are generally termed as "Unclassified Forests" (MFCC, 2020a; Oo et al., 2021). Under the current legal frameworks, timber can also be legally sourced from Unclassified Forests.

Unclassified Forests need to be understood in the historical context of the forest gazettement process in Myanmar. During the colonial period, forests were divided into "Reserved Forests" and "Un-class Forests (or Unreserved and Public Forests)." For administrative purposes, Reserved Forests were composed of "Compartments," and Un-class forests were divided into "Coupes." Terms have changed over time, and after 1992, some extent of Un-class Forests have formed as Protected Public Forests whiles others remained unclassified. Possible reasons for this may include a lower value or a less priority from a timber perspective, inaccessibility due to conflict, and remaining strong local customary claims (World Bank, 2019).

Also, it is crucial to understand Unclassified Forests from a jurisdictional perspective. The Forest Law (2018) designates the FD/MONREC as the competent authority for Forest Covered Land at the disposal of the government, which may include some Unclassified Forests. However, due to the overlapped land classification systems, land covered by Unclassified Forests is managed by MOALI, empowered by the VFV Management Law (amended in 2018). Because of how VFV land is defined, the term introduced by the VFV Management Law, most Unclassified Forests may fall within the land regarded as VFV land. The VFV Management Law provides MOALI with the authority to use VFV land for agriculture, livestock-farming, mining, and other businesses. In addition, due to the definition of VFV land, the community and customary areas may fall within VFV land. Although the Law stipulates the VFV land to exclude land being used under customary tenure, the frameworks are not yet in place to determine how this type of tenure will be determined and recognized (NAMATI, 2019; World Bank, 2020).

Forest Classification and its implications for the Timber Legality

By establishing the PFE (Reserved Forest and Protected Public Forest), given areas have a clear boundary with management objectives and are administrated by the FD/MONREC. According to the Forest Rules (2019), in establishing Reserved Forest, MONREC appoints a responsible

[2]The REDD+ Programme Myanmar (no date) defines forests with more than 40% canopy cover as "closed forests," while those with between 10% and 40% canopy cover as "open forests."

government officer and sets up a scrutiny body including local (ethnic) communities and relevant experts to inquire into and determine the affected rights of the public on a given land and to carry out demarcation. The appointed officer is responsible for conducting an inquiry on the claims of local people's rights and is empowered to modify proposed boundaries to exclude the land where the customary rights may be applied.

On the other hand, Unclassified Forests have not yet been reserved by the FD/MONREC, although some may historically have been managed or regarded as "Coupes" under the Myanmar forest governance system. Moreover, under the current legislation, Unclassified Forests are also categorized as VFV lands, which MONLI may regard as suitable for conversion to other land use, such as agribusiness concessions (Springate-Baginski et al., 2016). Overlapped with VFV land and customary land, Unclassified Forests include conflicting objectives and interests with competing jurisdictions and ambiguous tenure. Accordingly, Unclassified Forests may represent a problematic domain for timber production from the legality perspective compared with the PFE.

Timber Sources and Flows

According to the Forest Law (2018), all harvests on a commercial scale require a permit from the FD/MONREC. As sources of commercial timber, MONREC (2018) determines five broader categories (the way of log production), namely (1) Natural production forest under State management, (2) Natural Forest Logging Concession[3], (3) Natural Forest Conversion, (4) Plantations, and (5) Community Forests. In addition to these sources, (6) timber confiscated by the government enters supply chains after administrative and jurisdictional procedures.

Notably, the legal framework defines destination markets (for export and domestic uses) and forms of timber products according to the sources. For example, the Myanmar government introduced the log export ban in April 2014, and since then, Teak and other species have to be processed to export. Also, in 2017 the government decided not to use timber products derived from land conversion and confiscated timber for export (Forest Department, 2020). On the other hand, round logs from plantation forests are allowed to export after a case-by-case assessment since May 31, 2020, by Notification No 80/2019[4].

Harvest in Natural Production Forest under State management

This source is understood as selective logging of natural forests in specific reserved areas, mainly in Reserved Forests, but also in Protected Public Forests and Unclassified Forests under the disposal of the FD/MONREC.

The state-owned forest enterprise (Myanmar Timber Enterprise: MTE) has the sole rights for harvest from Natural Production Forest and sales of logs, as the designated state-owned enterprise for the forestry sector. The FD is responsible for selecting trees to be harvested and monitors the on-site logging activities of the MTE. Also, the FD conducts a post-harvest assessment with the MTE to ascertain the MTE's compliance with the logging regulations.

Under this form of harvest, a reserved area is divided into 30-compartments and harvested annually along with the District Forest Management Plan, following the annual allowable cutting (AAC), which limits the maximum annual exploitation within a given forest compartment. The FD determines the AAC based on the inventory in sampled forests every ten years, a felling cycle of 30 years, and minimum girth limits (Springate-Baginski et al., 2016; MONREC, 2018). This scientific forest management system is termed the

[3] There are no Natural Forest Logging Concessions currently granted (MONREC, 2018).

[4] There is no case of export of the logs from the plantation to date.

Myanmar Selection System (MSS). The specific and permanent number is allocated to each compartment[5], and all commercial logs extracted under the MSS are marked with necessary information (discussed below).

Logs from this form of harvest (hereafter MSS) are used for export and domestic consumption. Until 2017-2018, the MTE could subcontract the private sector for harvesting based on the in-kind timber allocation system, which is no more allowed. Accordingly, all logs harvested under the MSS are transported to the transit points of log distribution (MTE Agency depots). At the depots, the MTE classifies and separates logs for transporting to MTE Export Department depots in Yangon and for local sales through open tender (auctions). At local auctions, logs are sold for the private-sector wood-based industries that process and sell timber products for domestic markets (Banikoi et al., 2019). At Yangon depot, the MTE measures logs to determine their final sawing grades (SG)[6]and holds auctions for the private industries, mainly for export purposes. Generally, most harvested Teak is sold in log form to the private industries at auctions. The MTE processes about 25% of the harvested Teak into semi-finished and finished products, then sells them to the private-sector industries (ibid.). The World Bank (2019) reports that the MTE has been involved in direct export until recently.

Notably, the FD periodically publishes the AAC and annual logging outcomes under the MSS to the public. The AAC and logging data are divided into Teak, and other hardwood species. Figure 3 indicates serious over-extraction of Teak above the AAC until 2013-14[7]. However, a lack of commercially available Teak due to the past over-harvesting and the policy shift towards sustainable forest management led the FD to reduce the AAC substantially. The MTE also lowered the harvesting amount within the AAC from 2014-2015 (Figures 1 and 2). The current AAC is set at 19,210 trees for Teak and 592,330 for other hardwoods, and the MTE harvested 9,454 trees (corresponding to 14,943 hoppus tons) of Teak during 2017-18, reaching solely 49% of the AAC

[5] An example of the compartment number is "Sanda RF (89)". RF stands for Reserved Forest, and this compartment is numbered as 89th compartment within the Sanda Reserved Forest.

[6] Grades vary from SG7 to SG1, while the highest grade nowadays is SG4

[7] This large gap between the AAC and actual harvest volume might be caused to some extent as the harvest from Natural Forest conversion (development land-use projects) was counted into the total production, although the logs under such development projects were outside the AAC frameworks.

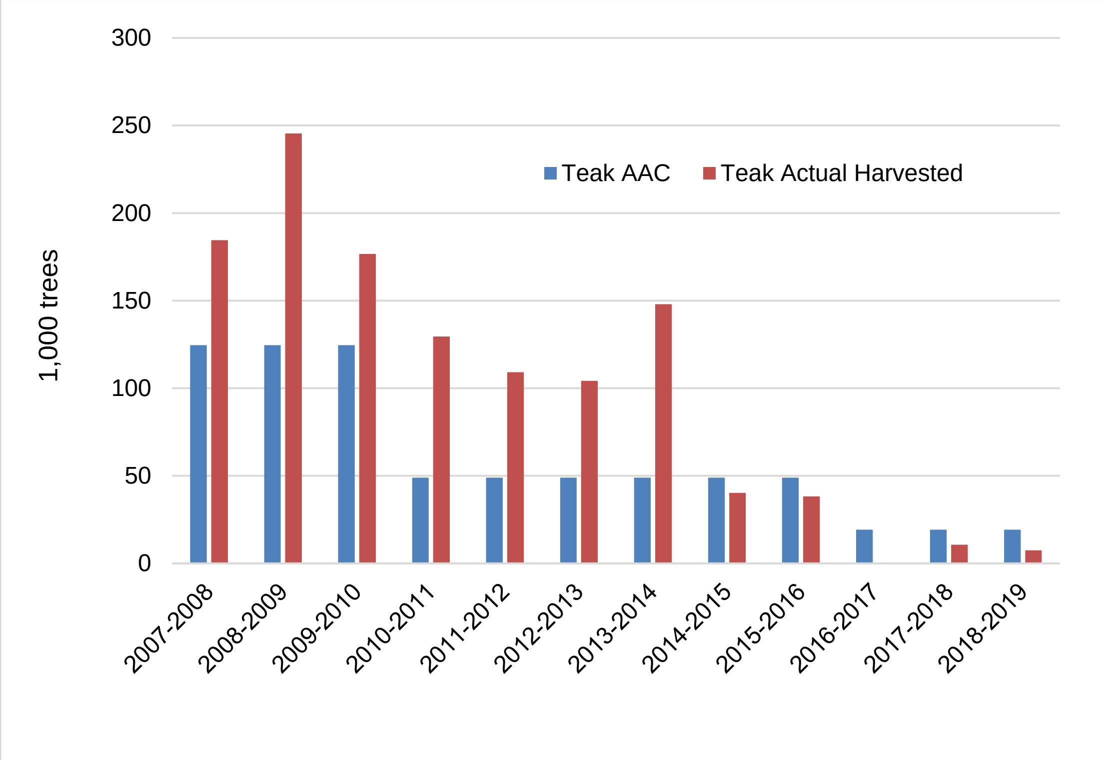


Figure 24-1 AAC and actual harvested teak trees in number
Source: Forest Department (2020) and Than (2020)

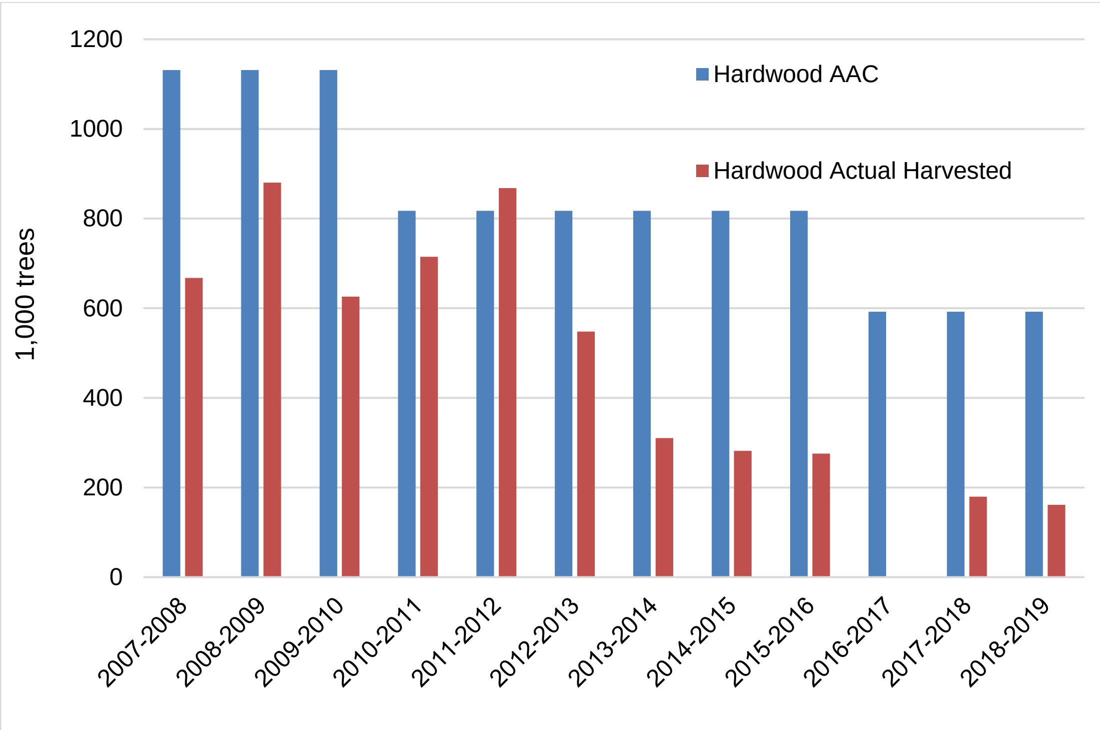


Figure 24-2 AAC and actual harvested hardwood in number
Source: Forest Department (2020) and Than (2020)

Natural Forest Conversion

Timber is produced by converting natural forest land for other land use objectives, such as oil palm plantations, mining, and infrastructure development. Such forest conversion is allowed within the PFE and Unclassified Forests, but presumably, it has occurred mainly in Unclassified Forests. The VFV Management Law regulates land conversion in VFV land, allowing up to 50,000 acres (20,234 ha) to be leased up to 30-years to private-sector investors, government entities, etc.

MONREC authorizes forest conversion, and the FD assesses the number of trees and volumes in a given area. Like harvest under the MSS, the MTE is responsible for the harvest and sales of logs (MONREC, 2018). However, timber production from natural forest conversion is not subject to the AAC framework. After harvest, commercial logs are marked to collect royalty. In 2017, MONREC decided not to use timber from the forest conversion for export. Since then, timber from this modality has been used only to feed domestic markets.

Our survey could not identify how many logs have been produced from the conversion of natural forests. Notably, Woods (2015) points out that the Myanmar government does not systematically collect the amounts of timber produced from agribusiness concessions, with a few exceptions. On the other hand, several studies suggest natural forest conversion as an important timber source. For instance, FAO-EU FLEGT Programme (2017) estimates that timber from land conversion accounted for around 16% of total extracted volumes in 2014-2015 and 8% in 2015-2016. Furthermore. the World Bank (2020) identifies more than 3 million m^3 in 2018 as a gap between harvested volume under the MSS and apparent total consumption (exports plus domestic use). It points out that forest conversion for agriculture and other development projects and informal and illegal harvests filled mostly this supply gap. Also, Springate-Baginski et al. (2016) estimate that nearly 10,000 trees (more than 25,000 hoppus tons) were harvested to convert Unclassified Forests in Kachin state in 2013-2014.

Plantation

About 30,000 ha of plantations have been established annually since 1984 for commercial, industrial, village supply, and watershed management objectives (Forest Department, 2020). Recently the government has strengthened promoting commercial timber plantations to reduce timber extraction from natural forests while meeting the demand. Since 2019-2020, annual Teak production has been targeted at 50 % from natural forests and 50% from plantations (MFCC, 2020b).

Commercial plantations need to be registered and harvested under the FD's approval and procedure. After harvest, commercial logs are marked to collect royalty. There are two types of commercial-scale plantations according to ownership types:

State-owned commercial plantation

State-owned commercial plantations have been established within Reserved Forest or Protected Public Forest. Annually, the FD and the MTE decide the number of Teak and other species to be harvested from State-owned plantations. As administrated separately from Natural Production Forests under the MSS, plantations are not subject to the AAC setting. The MTE has sole rights to harvest and sell logs. Those logs are distributed under the control of the MTE, the same as the timber flow from the MSS.

The Forest Department (2020) reports that the area of state-owned commercial plantations amounts to 491,403 ha as of 2018. However, its production was started recently from 30 years of age and above plantations. According to the MTE's presentation[8], Teak log production from state-owned plantations reached 1,509 hoppus tons (equivalent to 2,720.73 m^3 or 1,258 trees)[9] in 2018-2019 and 2,992 hoppus tons (equivalent to 5,394.58 m^3 or 1,995 trees) in 2019-2020. These amounts correspond to 13% in 2018-2019 and 59% in 2019-2020 against Teak production from the MSS, respectively.

Private plantation

In 2006, the government allowed the private sector to establish Teak and other hardwood plantations to accelerate the forestry industry. The legal frameworks have created the rights and opportunities for the private sector to harvest timber, transfer, produce value-added products and commercialize them.

Land for private plantations is available either by the PFE and VFV land lease or in large private lands under the authorization of the FD. As of 2018, the private sector has established 13,127 ha of Teak plantations and 16,220 ha of non-Teak forest plantations (Forest Department, 2020). However, private plantations are still at an early age, and exports have not yet been realized.

Community Forests

The revised Community Forestry Instructions (CFI) issued in 2019 has granted the community forest users groups (CFUGs)[10] trees and forest land tenure rights for an initial 30-year period, including harvesting and commercializing timber for export purposes. The scheme includes managing existing natural forests and establishing new plantations.

The community forests are found mainly in Protected Public Forest while being allowed within Reserved Forest, the buffer zone of Protected Areas, and even Unclassified Forests on VFV land. Since its introduction in 1996–1997, the scheme developed slowly, amounting to 49,216 ha in 2013-2014. Then the area has drastically increased, resulting in the establishment of 289,161 ha, covering 5,426 CFUGs (138,179 members) as of December 2019 (Forest Department, 2020). However, no community forests have begun commercial harvesting for exports to date.

Confiscated Timber

Confiscated timber can enter legal supply chains to fulfil the domestic need for timber but cannot be used for export purposes since 2017. The FD keeps the confiscated timber until the court determines the sentence (Rand et al., 2019), then it is delivered to the MTE or sold by the FD to the public.

The FD/MONREC has made efforts to prevent and prosecute illegal forestry operations and trades, and the FD reports all confiscated cases of illegal logging.[11] Between 2016 and 2020, more than 40,000 hoppus tons of timber were seized annually by the FD and other related departments (Japanese Forestry Agency, 2019).

Timber Supply Chains and Control

Based on the previous section, Figure 3 illustrates timber supply chains defined by the legal frameworks, including timber sources, actors, and how logs are distributed and used (i.e., domestic consumption or export purposes).

[8] MTE (n.d) Teak Marketing, Exporting & Market Situation (Provided from the MFCC)

[9] MTE's conversion rates: 1.8027 m^3/hoppus ton; and for teak 1.2 hoppus tons/tree (prior to 2018) and 1.5 hoppus tons/tree (since 2019)

[10] CFI (2019) determines CFUGs as a group formed by households who have lived continuously for five years in or within 5 miles of the periphery of the forest.

[11] https://www.forestdepartment.gov.mm/

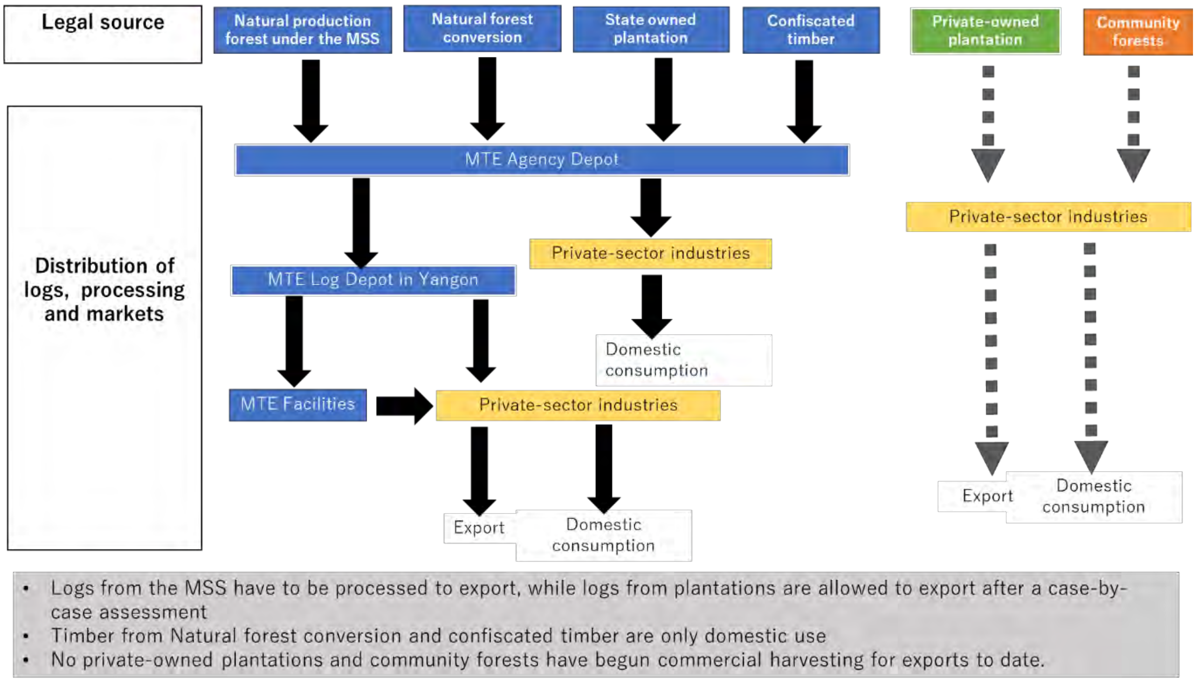


Figure 24-3 Timber sources and supply chains in Myanmar
Source: MONREC (2018), ICIMOD (2019) & Japanese Forestry Agency (2021)

Overview of Current Timber Sources and Supply Chains

For commercial purposes, the current timber sources are Natural Production Forest under the MSS and State-owned plantations and probably Natural Forest conversion. The MTE is responsible for the harvest, distribution, and sales of logs from these sources and processes some portions. Private industries process logs purchased from the MTE and export processed products or sell them for domestic use.

Notably, the destination market and the forms of products are different by source. For example, logs from Natural Forest conversion are domestic use only. On the other hand, logs from other sources are used for both export and domestic consumption. Notably, logs from the MSS need to be processed for export, while those from plantations can be exported case-by-case assessment.

To assist traders in demonstrating that the timber was legally sourced, MONREC published the CoC Dossier in 2018 as a part of efforts to establish the timber legality assurance system. It describes 30 detailed steps of the timber supply chain under the MSS, from the AAC setting to product export, and gives examples of documents/forms used at each step with English translation. By making information on supply chains and associated documents to the public, the CoC Dossier can be viewed as a strong commitment of the government to promote transparency in timber supply chains. Also, the transparency is addressed by the publication of the AAC and the actual harvest volume from the MSS and plantations. While some studies such as Forest Trends (2021) and the World Bank (2020) point to uncertainty or discrepancies in production data, the periodic disclosure of production volume helps to demonstrate the government's efforts to account for their forest management and monitoring towards legal and sustainable forest management.

On the other hand, harvest volume from Natural Forest conversion has not been opened to the public, which undermines the government's efforts to improve transparency in timber production and supply chains. Furthermore, the fact that issues of Natural Forest conversion are not well determined in the provision of the Forest Law (2018) and the Forest Rules

(2019) also can increase concerns. International stakeholders may see the absence of production data and unclear framework as a lack of transparency and weakness of the government control over timber production and flows.

Mechanisms and tools to control and monitor timber supply chains

Currently, Myanmar applies physical marking and paper-based systems that monitor and control the timber production and supply chains.

Physical marks on logs

The Forest Law (2018) stipulates that "*a person who has obtained permission for extraction of forest produce shall affix the mark after measuring in the manner prescribed or affix the property mark which has been registered*." Indeed, each MTE Extraction Agency has its hammer registered by the FD. Also, the Forest Rules (2019) defines that the private marking hammer or the stamp of the community forest shall be affixed on the logs respectively in the extraction of timber from private plantations or community forests. In addition, several other marks are placed on logs harvested commercially, which help identify logs, such as species, grade, district of origin, and extraction year.

Figure 24-4 shows an example of such marks on a log produced from the MSS. In addition to the MTE Agency Mark, the revenue mark and tree number provide essential information to track the origin of harvest. As mentioned above, logs harvested commercially are subject to levy. For this purpose, after the FD and the MTE jointly measure logs at log landing points, the FD places the revenue mark and number, and records them. An example of the revenue mark is given in Figure 24-4 as "SG/B2/15", whose first two letters (SG) stand for "Sagaing" region, the following letter and number (B2) indicate "district" and "township", and the last number (15) represents "the year 2015 (harvest year)". The revenue number (e.g., 1402 in Figure 24-4) is allocated consecutively for all logged compartments within a given township. The standing tree number (e.g., 305 in Figure 24-4) is sequential for all marked trees to be harvested per compartment.

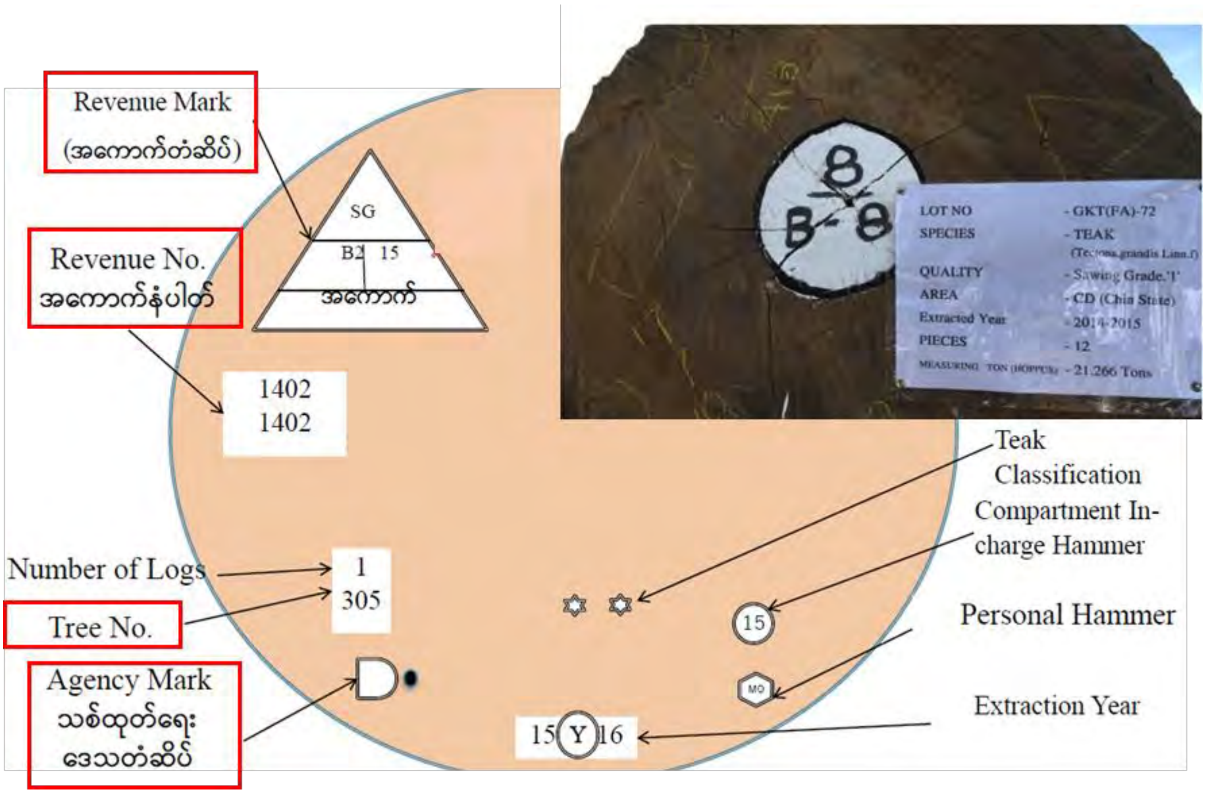


Figure 24-4 Marks on bucked log
Source: FAO-EU FLEGT Programme (2017) and the picture taken by the MFCC

The marks are visible until processing logs. In other words, supply chain actors, including the private-sector industries that buy logs from the MTE, can visually identify the origin of harvest at a township level. However, the marks may sometimes be difficult to read due to being partially visible or missing (FAO-EU FLEGT Programme, 2017).

Paper-based information system to monitor supply chain

Based on the CoC Dossier published by MONREC (2018), Table 24-3 summarizes key documents/forms used at each step in the timber supply chain originating from the MSS. It describes types of recorded information that help identify the origin of logs and indicates how these are transmitted to the next step along the timber supply chain.

Table 24-3 Key documents and information included in timber supply chain from log landing to private processing facilities

Step	Document/ For	Description	Species name	Log dimensions	Revenue Mark	Tree no.
Log measurement at the log landing points	Measurement Book	• Record measurements of harvested logs • Sent to the MTE Agency Depot prior to the log transportation	Yes	Yes	Yes	Yes
Transportation of logs to MTE Agency Depot	Transportation document	• Accompany to logs • Revenue mark is not included, but contains information of the MTE Agency and the compartment in which the logs were harvested	Yes	Yes	Unidentified	Yes
Receiving logs at MTE Agency Depot	Register Book	• Register log information by truck, compartment and species	Yes	Yes	Yes	Yes
Log transportation to MTE Depot in Yangon	Transportation document	• Accompany to logs • Trucking slip is used for transporting logs by truck, while AT, AU, and AS forms are for other transport means (barge, raft and train) • Revenue mark is not seen in Trucking slip, but it includes information of the MTE Agency and the compartment	Yes	Yes	Unidentified	Yes
Receipt of logs at MTE Yangon Depot	Register Books	• Register serial number of transportation documents, Depot entry number, Depot of origin, and lot number which logs are assigned for sale	Yes	Yes	No	Yes
Sales of logs to the Private sector	Specification and other sales documents	• Prepared by the MTE for log sales and attached to logs • Include lot number, Depot, Agency of origin, and buyer. • Since 2017, include information on the revenue mark and the tree number	Yes	Yes	Yes	Yes

Author's own compilation based on the CoC Dossier (MONREC, 2018)

Species names and log dimensions are recorded at each step, from log landing points to sales of logs to private buyers. Recording such information at each step enables the FD to monitor the overall movement of logs based on a systematic understanding of inputs, outputs, and accumulations at each point.

The revenue mark informs the township where a given log was harvested, and the tree number indicates individual tree identification within a given compartment. While the revenue mark may be missed in some documents/forms (Table 24-3), notably since 2017-2018, the revenue mark has been recorded in "Specifications," which is used for the sales of logs at the MTE Log Depot in Yangon to private industries. This means that currently, private industries can identify the origin of logs at a township level.

It is important to note, based on on-site visits, Sloth & Htun (2020) conclude that it is possible to trace back from log depots at sawmills to the district of origin using the relevant forms and documents combined with the hammer marks on logs. Nevertheless, it may be necessary to ensure that all documents and forms register the revenue mark to hold the accountability of legal origin at each step and show links between them, from transporting logs from forests to sales to private buyers.

The revenue mark system is applied to commercial log extraction from all sources, identifying the origin of harvest at a township level. However, the revenue mark (e.g., SG/B2/15) does not distinguish the source (i.e., Natural Production Forests under the MSS, State-owned plantations, and Natural Forest conversion) where logs were harvested. Indeed, Sloth & Htun (2020) report that it was impossible to confirm whether the logs originated from plantations or natural forests. This may be explained that the revenue mark system was developed to collect harvest royalties as its name suggests and does not intend to trace the origin of harvest.

Segregation at MTE depots

Generally, logs are sorted, compiled, and traded according to their quality (grade). In Myanmar, one lot consists of logs of the same grade composing a minimum of ten pieces[12]. Notably, the MTE (2017) declared that *"logs from same harvesting area would be piled to one lot in order to clarify the source of timber origin for logs which would be extracted in 2017-18 and forward"*. This statement gives a positive signal to buyers who want to ensure the origin of logs. Nevertheless, it should be noted that the MTE's focus is on "harvest location" and not "timber source (i.e., the MSS, State-owned plantations, and Natural Forest conversion). In addition, the MTE's efforts may face the following challenges. First, as mentioned above, to guarantee a better economic return, one lot needs to be made up of logs at the same grade. Secondly, valuable species of larger size, such as Teak, are found in relatively small proportions in natural forests (Kollert & Kleine, 2017). Thirdly, the FD has drastically reduced the logging intensity under the MSS (see. Figures 24-1 & Figures 24-2). These make it challenging for the MTE to compile lots of quality logs from one area. Accordingly, the MTE likely has to gather logs of different grades, which lowers the grade of lots on average, leading to an economic disadvantage for the MTE. In addition, this attempt may also present a problem for buyers in obtaining quality logs.

Monitoring and control of processing at private industries

The CoC Dossier describes the procedure at the stage of processing logs in the private industries as below. First, the FD inspects the logs against the attached documents

[12] In the Myanmar Grading System, Sawing Grade (SG) 1 is the highest log quality, followed by SG2, 3, and the lowest 5 to 7.

when private industries receive logs from the MTE. Then, private industries have to obtain a permit to process the inspected logs from the FD. Notably, MONREC has determined the conversion ratios from round log to product per Teak and other species. After processing, private industries have to report the production amount to the FD. In addition, when private industries export their processed products, the FD examines the products to determine whether possible unspecified logs have entered production.

These procedures enable the FD to observe the movement of logs and timber products to the point of export. By systematically monitoring and registering incoming logs, outturn products, and accumulating volumes at all private industries, the FD can have overall mass-balance control to avoid entering unknown-sourced logs in the timber supply chain.

However, the CoC Dossier does not explain the procedures and control measures at the secondary processing stage (e.g., transporting sawn timber froman industry to a downstream one and processing it into finished products such as furniture). Indeed, the FAO-EU FLEGT Programme (2017) concludes that tracking input materials through production to the final product is not addressed in the Myanmar system.Also, it does not describe the procedures for processing logs at the MTE facilities and sales of their semi-finished products to the private industries.

Conclusion

For producer countries, the potential to participate in expanding regulated markets rests on the national ability and commitment to hold accountability for the legal origin of timber products. Given this understanding, the Myanmar study has discussed its forest classification, timber sources, supply chains, and measures to support tracking and ensuring the legal origin of timber and explore opportunities and constraints to promote legal timber production and trade.

In Myanmar, timber is legally harvested in the PEF and Unclassified Forest. While the harvest volume from Unclassified Forest is likely smaller than from the PEF, Unclassified Forest may represent a problematic domain for timber production from the legality perspective. First, overlapping jurisdictions and competing objectives over Unclassified Forest may hamper effective forest management, monitoring, and law enforcement. Second, the lack of robust demarcation procedures and opportunities to consider local people's rights may weaken claims for the legal basis. Hence, the current measures to control and trace supply chains focusing on the origin of harvest by location (at a township level) may need to consider the forest types.

The current timber sources at a commercial scale are Natural Production Forest under the MSS and State-owned plantations and probably Natural Forest conversion, all of which are managed by the MTE. The issue of transparency in timber production in Myanmar has been enhanced by the disclosure of planned and actual harvested volume from the MSS and State-owned plantations. On the other hand, the absence of available production data from Natural Forest conversion and its unclear framework compared with other timber sources may undermine the overall efforts of the forestry sector in Myanmar to increase transparency over timber production and distribution.

Currently, Myanmar applies physical marking and paper-based systems that monitor and control the timber production and supply chains. The study has identified increased efforts and several measures by the government to improve transparency and traceability along the timber supply chain. For instance, the publication of the CoC Dossier is remarkable in this regard. Also, the MTE's attempt to implement a segregation system and include the revenue mark in the sales document helps track the legal origin of timber. However, the study has also identified issues to be considered. First, given the difference in the markets and allowed product forms to export by timber source, it is crucial to distinguish and demonstrate the origin of harvest not only by location (i.e., township) but also by timber source and forest type from which timber was harvested. Secondly, the current system enables trace logs from log yards of private industries to a township of harvest. However, it may be necessary to enhance these ongoing initiatives and measures. For instance, the scope of the CoC Dossier could be broadened from the current focus on the MSS to other timber sources, as well as coverage of products (from the current focus on logs to processed and finished products). Such effort can promote legal timber production and trade while enhancing transparency and traceability of overall timber supply chains and delivering positive signals to concerned actors.

These findings and discussions include lessons for producer countries to enhance the production and trade of legally harvested timber products. Firstly, the accountability of the legal origin of timber products needs to consider not only locations where timber was harvested but also focus on the types of timber source and forest since each source (e.g., selective logging, forest conversion, and plantations) and/or forest type may associate with particular risks, considerations, and implications for a legal basis. Also, Myanmar's case illustrates several measures to increase traceability and transparency of legal origin. However, the case indicates that such efforts may need to be undertaken with the ongoing forestry sector reform and business practices. Generally, the distribution and sale of timber are based on quality and quantity and not on legal origin. Hence, the supply chain management was not originally designed to trace the origin and inform concerned actors, especially downstream businesses, about from which a product comes. At the same time, demand-side countries need to understand the situation and challenges that producer countries may have to address these issues.

Lastly, there is a growing demand for not only legal timber products but also those that are sustainably harvested in the context of achieving sustainable development goals and climate change mitigation, resulting in more attention paid to the origin of the product (e.g., from which forest and how timber is harvested). Accordingly, together with legal and sustainable forest management, establishing transparent and traceable timber supply chains will provide timber producer countries with more opportunities to participate in global markets while addressing global environmental issues.

References

Arts, B., Heukels, B. & Turnhout, E. (2021). Tracing timber legality in practice: The case of Ghana and the EU. *Forest Policy and Economics,* 130(102532), 1-9.

Banikoi, H., Karky, B. S., Shrestha, A. J., Aye, Z. M., Oo, T. N. & Bhattarai, N. (2019). *Promoting REDD+ compatible timber value chains: The teak value chain in Myanmar and its compatibility with REDD+*. ICIMOD Working Paper 2019/3, Kathmandu, Nepal.

Bartley, T. (2014). Transnational governance and the re-centered state : Sustainability or legality ?. *Regulation & Governance,* 8(1), 93–109.

Brown, D., Schreckenberg, K., Bird, N., o Cerutti, P., Gatto, F. D., Diaw, C. et al. (2008). *Legal timber: Verification and Governance in the Forest Sector*. Overseas Development Institute. London. http://www.odi.org.uk/resources/docs/3472.pdf.

FAO-EU FLEGT Programme. (2017). *Myanmar Timber Legality Assurance System (MTLAS) Gap Analysis Project Final Report*.

Fay, C. & Michon, G. (2003). Redressing forestry hegemony - Where a forestry regulatory framework is best replaced by an agrarian one. In: *The International Conference on Rural Livelihoods, Forests and Biodiversity*, pp. 1-18. 19-23 May 2003, Bonn, Germany.

Forest Department (2020). *Forestry in Myanmar 2020*. https://www.forestdepartment.gov.mm/sites/default/files/Documents/Forestry_in_Myanmar_2020_0.pdf.

Forest Trends (2021). *Illegal Logging and Associated Trade in Myanmar: Impacts of Government Measures to Address Illegal Logging*. https://www.forest-trends.org/publications/illegal-logging-and-associated-trade-in-myanmar/.

Japanese Forestry Agency (2019). *Lao PDR Country Report: Clean Wood survey*, *Journal of Weed Science and Technology. Supplement*.

Japanese Forestry Agency (2021). *Myanmar Country Study under the Clean Wood Information Collection Project,* Japan. (in Japanese). https://www.rinya.maff.go.jp/j/riyou/goho/jouhou/pdf/r2/r2report-logging_3.pdf.

Kollert, W. & Kleine, M. (2017). Introduction. In: *The Global Teak Study Analysis, Evaluation and Future Potential of Teak Resources*. (eds. W. Kollert & M. Kleine), pp. 15–16. International Union of Forest Research Organizations, Vienna, Austria.

MFCC (Mel Frequency Cepstral Coefficients). (2020a). *First Draft Myanmar Timber Legality Assurance System. (MTLAS): MTLAS Std1LS*, Yangon, Myanmar.

MFCC (Mel Frequency Cepstral Coefficients). (2020b). *State-owned Teak Plantation Timber Harvesting and Exporting Procedure Introduction*, Yangon, , Myanmar. https://myanmarforestcertification.org/wp-content/uploads/2021/01/Plantation-Extraction-Procedure_ENG.pdf

Mol, A. P. J. & Oosterveer, P. (2015). Certification of markets, markets of certificates: Tracing sustainability in global agro-food value chains. *Sustainability,* 7(9), 12258–12278.

MONREC (Ministry of Natural Resources and Environmental) (2018). *Myanmar Timber Chain of Custody Process Documents and Actors*. https://www.forestdepartment.gov.mm/books/other/myanmar-timber-chain-custody-process-documents-and-actors.

MTE (Myanmar Timber Export). (2017). *Current situation of Myanma Timber Enterprise and the future plans & documentation for Myanmar Timber export (2017)*. http://www.mte.com.mm/index.php/mm/announcements-mm/1069-1051-15-8-2017-02.

NAMATI. (2019). *Most Farmers Do Not Know about the Vacant, Fallow and Virgin Land Management Law as the Grace Period to Register Closes*. https://namati.org/resources/most-farmers-do-not-know-about-the-vacant-fallow-and-virgin-land-management-law-as-the-grace-period-to-register-closes/.

Oo, T. N., Hlaing, E. E. S., Aye, Y. Y., Chan, N., Maung, N. L., Phyoe, S. S., Thu, P. et al. (2020). *The Context of REDD+ in Myanmar: Drivers, Agents and Institutions*. Occasional Paper 202, Bogor, Indonesia.

Rand, J., Rodriguez, P. C. & Tarp, F. (2019). *The governance of global value chains , the state , and small businesses The case of timber in Myanmar*. WIDER Working Paper 2019 / 78, Myanmar.

REDD+ Programme Myanmar (n.d.). *Draft National REDD+ Strategy Myanmar*.

Seidel, F. (2011). *DRAFT REPORT TIMBER TRACKING TECHNOLOGIES Review of Electronic and Semi-Electronic Timber Tracking*. https://www.itto.int/files/user/pdf/Meeting related documents/Timber Tracking Review.pdf.

Sloth, C. & Htun, K. (2020). *Evaluation of the Myanmar CoC Dossier and MTLAS: Report developed on behalf of European Timber Trade Federation*. https://preferredbynature.org/sites/default/files/2020-03/CoC-Dossier-and-MTLAS-evaluation-19FEB20.pdf.

Smith, W. (2002). The global problem of illegal logging. *ITTO Tropical Forest Update,* 10(1), 3–5.

Springate-Baginski, O., Treue, T. & Htun, K. (2016). *Legally and illegally logged out The status of Myanmar's timber sector and options for reform*. http://www.burmalibrary.org/docs24/Springate-Baginski_et_al-2016-status.pdf.

Than, S. (2020). *Sustainable supply and value chains of quality Teak timber in Myanmar*. National Teak Forum in Lao PDR, Laos.

Tint, K., Springate-Baginski, O. & Mehm, K. K. G. (2011). *Community Forestry in Myanmar : Progress & Potentials*. https://data.opendevelopmentmekong.net/library_record/community-forestry-in-myanmar-progress-and-potentials.

Woods, K. (2015) *Commercial Agriculture Expansion in Myanmar: Links to Deforestation, Conversion Timber, and Land Conflicts.* https://www.forest-trends.org/publications/commercial-agriculture-expansion-in-myanmar-links-to-deforestation-conversion-timber-and-land-conflicts/.

World Bank (2019) *Myanmar Country Environmental Analysis: Forest Resources Sector Report*. World Bank, Washington DC, USA.

World Bank (2020) *Incentivizing Sustainable Private Sector Investment in Timber Plantations in Myanmar : Policy Options to Encourage Socially and Environmentally Responsible Investment*. World Bank, Washington DC, USA.

Chapter 25: Teak in Mekong: Governance Concerns and The Evolving Policies

Promode Kant

Abstract

Teak (*Tectona grandis*), ideal timber for ship building and declared royal tree the felling and sale of which required specific permission, was the primary reason for attracting European colonial powers to the Mekong region, the two British-Burmah wars, and the annexation of lower Burmah to the British Empire. In 1855 the British, through the "Minutes on Forest Policy", declared forests to be the property of the state, subordinated private interests to the rights of the State over nature, and got the State involved in all forestry operations directly. Brandis translated into practice what scientific forestry actually meant in tropical forests, introduced the concept of annual allowable cut, and innovated the agroforestry practice of Taungya as an early prototype of sustainable forest landscape management by communities. Current policy emphasis across the region is on the ecological values of forests with prohibitions on harvesting in natural forests except in Myanmar where, too, strong prescriptions in favour of sustainable forest management have been imposed on tree felling. Planting teak over private lands, particularly by smallholders, is encouraged but there are a host of policies, laws, practices, and scientific and managerial concerns that discourage private sector investment in teak. This chapter presents the evolution of teak related policies in the Mekong region since the nineteenth century till date, examines the difficulties experienced by smallholder teak planters, and suggests way forward.

Introduction

Teak is known the world over for its wood quality and attractiveness, combining strength with lightness, durability, dimensional stability, non-corroding properties, ease of working and seasoning and, no less, for its famed resistance to termite, fungus, chemical, water and weather (FAO, 2009). It is able to withstand changes in moisture without much shrinking and, for this reason, has been used in ship building for at least two thousand years and, in building smaller boats in India and its neighbourhood, for almost as long as boats have been used by man.

It is this quality of teak that saw its importance grow multifold around the fifteenth century when several European countries vied with each other to expand their navies for colonizing the world. Large and sturdy ships were the primary vehicles of large-scale trade and prosperity, and naval power mostly decided the place of nations in the global power structure. European travellers brought home the tales of the majesty of teak and of the immense wealth growing in the teak forests of the India and Indo-China waiting to be exploited and their traders followed in large numbers petitioning kings and warlords for permission to cut and carry teak. Within a few decades these stray trades in teak were catapulted into some of the biggest and most powerful companies the world has ever known, all heavily backed up by their governments marking the beginning of colonization of the huge swathe of lands across the tropical Asia.

Teak trees to teak concessions

Before the entry of European colonial powers in the Mekong sub-region in the 18th century, the forests unlike cultivated lands, were under the direct control of the local rulers but free access to timber and other forest resources was usually accorded to people in the neighborhood with some oversight to ensure, when used for trade, the local rulers also get a part of the earnings. Since mostly teak was used for trade across the borders, and the primary end use was military, the kings of the region, like the Alaungpaya dynasty of Myanmar, declared it as Royal tree the felling, transport and sale of which required permission from local authorities. As export demand for teak, mainly for naval ship for expanding empires and establishing businesses across the globe, increased the rulers began allotting blocks of forests for a price permitting the purchaser to fell mature trees as needed and take out of the country.

With the entry of the colonial powers these felling operations, hitherto limited by the financial capacities of the forest lessee, covered far greater areas and destruction became evident everywhere. In 1826 Tenasserim and Martaban provinces of Burmah were ceded to the British East India Company under the Treaty of Yandaboo and in 1827 Dr Nathaniel Wallich, Superintendent of Botanical Garden at Calcutta, reported that the forests of the province were better than anywhere else under the East India Company's sphere of influence. There was a rush to exploit these forests and in 1829 these forests were thrown open to any exploiter who could pay the *ad-valorem* value on the timber taken out of the forests to a port of exit. This method was difficult to supervise and Moulmein, barely a large village, soon became an important town, and within twenty years the whole of the population were immersed in the teak industry (Stebbing, 1947).

Uncontrolled felling in the teak forests of Burmah under British influence continued causing serious concerns in the trade and political circles and, in 1837, the East India Company sent Dr Johann Wilhelm Welfer, an eminent Naturalist of the time, to examine the status of forests of Tenasserim. Welfer confirmed the worst fears reporting low teak inventories and inadequate regeneration. He recommended raising teak plantations rather than relying exclusively on natural forests. Welker's report led to the cancellation of all existing teak extraction leases in 1841 by the new Superintendent of Forests, Captain Tremenheere, and fresh leases were granted with sufficient safeguards.

But there were no effective mechanisms to enforce the safeguards in the forests and the enforcement of regulations at the port of exit, when timber had already been felled and transported at considerable expenditure, led to strong protests from the business community. The East India Company decided in favour of the traders overruling the Superintendent and allowed the former system to prevail. The destruction of natural teak forests of Tenasserim continued.

The prospering of the colonial merchants at the cost of local resources and the native people angered the local chieftains and the King and there were complaints of extortion of British merchants by the local gangs suspected to be backed by the Burmese King. This ultimately leads to the Second British-Burma war of 1852-53 as a result of which the British annexed large parts of Lower Burma including the province of Pegu (now called Bago) with its teak forests reckoned the best in the whole world. This time, however, the East India Company declared that "all the forests are the property of the Government, and no general permission to cut timber therein will be granted to anyone" (Barton, 2002) and appointed a new Superintendent, Dr John McClelland, to manage the Pegu forests (Figure 25-1).

The beginnings of policies that encouraged sustainable management in Burma

McClelland noticed harvesting was concentrated along the lower hills and along streams with heavy felling of young trees as it was guided by ease of access and transport of harvested timber rather than age of trees. He wrote a detailed report to the then Governor General of East India Company in Calcutta a single sentence of which, quoted countless times, contains the central principle of scientific forestry: "A forest may be regarded as a growing capital, the resources of which are the young trees, and unless these are preserved and guarded to maturity, it is obvious the forest must necessarily degenerate from the nature of an improving capital to that of a sinking fund." (Handel, 2012). In order to discourage harvesting of younger trees McClelland recommended marking of trees for harvest to be undertaken by the government rather than merchants and levying duty on logs by number irrespective of the value of logs (Stebbing, 1922).

MacClelland's report led to the famous "Minutes on Forest Policy" of 1855 by Governor General Lord Dalhousie of the East India Company that initiated a new approach to forest management in which all teak was declared the property of the state, private interests were subordinated to the rights of the state over nature, and the state was to be involved in all forestry operations directly, deciding how much to harvest annually, marking specific trees for felling, and transporting harvested products to the depots. The Minutes were critical of the monopolistic role of big timber traders and favored smaller traders over the larger ones for harvesting and transport of timber on behalf of the government (Handel, 2012).

Taungya in teak

It fell to Dr Dietrich Brandis, who succeeded McClelland as the Superintendent of Pegu forests in 1856, to translate into practice what scientific forestry actually meant in tropical forests. He made an estimate of what could be the annual allowable cut from the forests of Pegu spread over some eight million hectares. More important, Brandis devised a way in which the people of Pegu, the Karen, considered hostile to the British, could benefit from the increasing value teak was offering. Till then the Karen people, practicing shifting cultivation, would clear a patch of forests by felling and setting fire to the vegetation and mixing ash with the soil, cultivate for three years, and then return to the same site after 15 to 20 years. Brandis offered them an attractive sum of money if they also planted teak along with their crops and left a certain number of sturdy teak saplings behind as they moved to the next site for growing their food. Thus was born the novel agroforestry practice of Taungya that then quickly spread across the colonized tropical world, an early prototype of sustainable forest landscape management by communities.

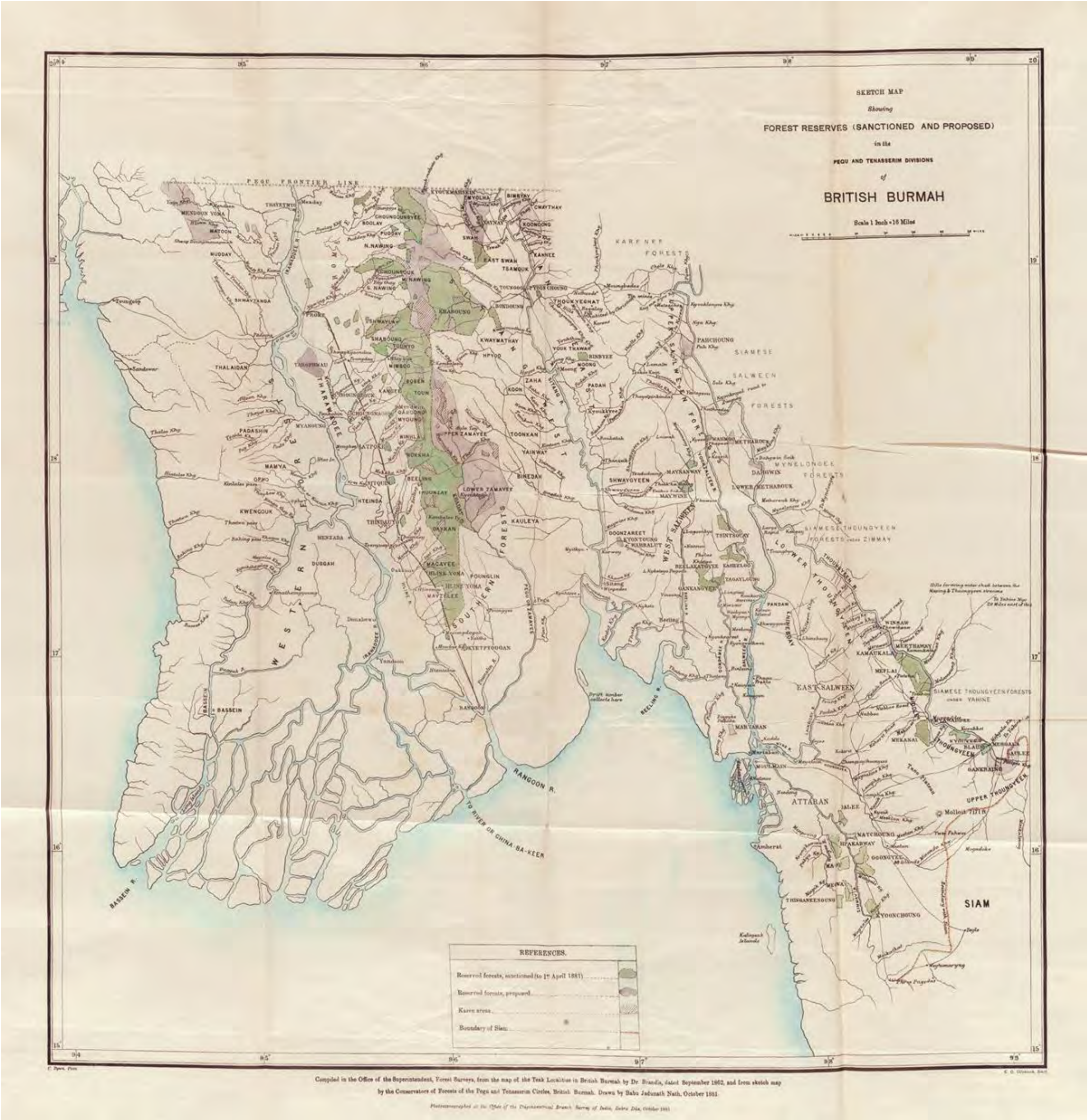


Figure 25-1 Sketch map of the existing and proposed forest reserves in Pegu and Tenasserim divisions of British Burmah in 1861. The Karen areas and the boundary of Siam at that time are also shown (Source: Into the Woods by Dan Handel, Cabinet Magazine, Issue 48, 2012)

Expanding the British teak net towards Siam

By 1850s the British knew the teak resources in Burma would not last long at the rate they were being exploited. So they cast their eyes on the considerable teak forests of Siam as Thailand was then known. From the eastern side the rival French East India Company, which had already established its zone of influence across Vietnam, Laos and Cambodia, were waiting for their own opportunity at the door of Thailand. The French objectives was more political than commercial with rather limited French influence in timber related policies in these countries where timber harvest and trade practices had evolved in response to the demands from the neighboring markets of China. Changes were slow and limited by the decentralized nature of political control in these countries with remarkable autonomy in the hands of local tribal communities.

The primary British goal from the mid 1850s to the 1880s was to make sure that the monarchy in Bangkok protected British merchants' access to teak in northern Siam but with the entry of the Bombay Burma Trading Corporation into the Siamese teak market in the 1880s the British actively sought to help large British trading firms gain a foothold in the lucrative northern Siamese teak market as a way of stopping French colonial expansion and accessing the great teak resources of the country for further strengthening their Navy. The British thus created their monopoly over teak trade in the world with the three sources of teak – India, Burma and Thailand – firmly under their control. Adjusting itself deftly between the two big powers of the day, Thailand remained politically independent but had to cede control over its teak forests in northern territories to the British. King Mongkut of Siam, after signing the Bowring Treaty in 1855 giving the British extraterritorial privileges in managing teak trade in the northern vassal states with the British Vice Counsel in Chiang Mai holding magisterial powers of the Court to settle trade disputes involving British subjects, famously stated his choice was whether to swim upriver and make friends with the crocodile (the French) or to swim downstream to the sea to be with the whale (the British). He obviously found the whale, that kept a cuddly but firm hold for the next three quarters of a century, a more manageable partner (Barton & Bennett, 2010; Tarling, 1993).

Thailand also benefited from this arrangement beyond the primary desire to keep the French 'crocodile' away. British foresters organized the Royal Forest Department of Thailand and led it from 1896 to 1925 and the Royal Thai Government used the fear of British annexation to keep the local chiefs of northern Siam under control during a politically turbulent period and bring a measure of centralized forest management and scientific forestry in the country (Barton et al, 2010). Forestry officials were trained in British established forestry institutions in India, a practice that continued well into 1970s.

Current policies related to teak

Over the past three quarters of century since the end of Second World War Forest policies across the world have gone through fundamental changes and the Mekong region is no exception. The emphasis is now increasingly on the ecological values of forests and less on the expectations of economic returns and this is particularly true for natural forests. There are prohibitions on harvesting in natural forests except in Myanmar where too strong prescriptions in favour of sustainable forest management have been imposed on tree felling. Country specific policies have been discussed below.

(i) Thailand

National Forest Policy of Thailand of 1985 required that of the total land area at least 40% (20.48 million ha) should be under forest cover with 15% kept for conservation forest and remaining 25% designated as production or economic forests. The massive floods that engulfed southern Thailand in November 1988 was, in popular perception, caused by deforestation and forest degradation due to excessive timber exploitation. Information derived from LANDSAT imageries in 1989 indicated that the total forest area had shrunk to just about 28%, about 12% below the targeted 40%. A complete logging ban over the whole country was introduced in January 1989 to protect the remaining forest resources and environment (Sumantakul & Sangkul, 1998).

The National Research Council of Thailand, asked to examine the situation, found that inconsistent strategies for management and protection of natural forests, poor law enforcement, and lack of money for ensuring proper conservation were the factors affecting the extent and quality of forest lands under conservation.

In the case of production forests the reasons identified were failure to amend management procedures in concession areas and small community forests to ensure sustainability, large wastages in the utilization of wood harvested from forests, and lack of proper utilization of cheaper timber species (Sumantakul & Sangkul, 1998).

In the Seventh National Economic and Social Development Plan (1992-96) that followed the disastrous floods of 1988 a much higher value was placed on the need for total conservation with 25% of the total land area of the country mandated for complete protection as watersheds, national parks, and wildlife preservation sanctuaries and 15% for production forests. Lands with slope of more than 35% were to be designated as forest lands for which no title deeds or land use certificates could be issued. And, in order to reach the overall 40% forest land target in the earliest possible time, it was decided to increase reforestation drive in both public and private sectors, amendments of laws and regulations that restrain reforestation in private sector, provision of extension services aimed at wise land use, re-organisation of National Forest Administration and explicit guidelines and penal code for dealing with forest destruction (Sumantakul & Sangkul, 1998).

In keeping with the provisions of this plan Forest Plantation Act was promulgated in February 1992 which enables people to plant forest tree species on both private and government lands and seek registration for their plantations. The ownership of these plantations is transferable both by succession and sale. Harvesting of timber and other forest products and their transport from plantation areas can be done with ease the only requirement being that the Forest Officer in-charge of the area should be informed of logging activities in advance so that he can issue a permit within 15 days. No fee is payable for harvesting in forest plantations both on private and government lands, or for their transportation (Sumantakul & Sangkul, 1998).

The Forest Plantation Act was amended in 2015 and the amended Section 10 now further removes the difficulties faced by plantation owners in harvesting and transport of the wood product of 58 tree species, of which teak is listed at number 1, annexed to the Act. It reads: “In logging the wood derived from forest plantation, the forest plantation operator may cut down the tree, cut lumber, trade, possess, and carry in transit the wood at the forest checkpoint without having to apply for permission under the law on forestry” (RGoT, 2015).

The amended Act of 2015 also has provisions for forest certification under Section 8/1 which now reads: “In case where the import of the log derived from forest plantation need to have a certificate of sustainable forest management form the Royal Forest Department required by the country of destination, or any forest plantation operator wishes to have a certificate of sustainable forest management issued by the Royal Forest Department, an application shall be filed with the Registrar and the expense incurred from the examination or any other operation in accordance with the rule prescribed by the Director-General shall be paid therewith (RGoT, 2015).

“The application for, issuance and revocation of the certificate under paragraph one shall be in accordance with the rule, procedure, and condition prescribed in the Ministerial Regulation; provided that it must be prescribed in accordance with the generally accepted international standard.

“The Director-General shall have power to authorize other institution or organ in issuance of certificate of sustainable forest management in his or her place” (RGoT, 2015).

(ii) Lao PDR

The natural teak forests of Lao PDR are a continuation of the teak forests of Myanmar and Thailand covering approximately 15% of the total forest area, mostly in Xayaboury and Bokeo provinces. The resource is depleting rapidly in area and stocking due to population pressure, shifting cultivation and forest fires. National Conference on Forestry of May 1989 reviewed government policies on the utilisation and management of natural resources and recommended (a) protection and rehabilitation of biological resources of existing forests, (b) maintaining the economic utility of forest resources, and (c) settlement of upland people dependent on shifting cultivation and ensuring their food security (DoF Lao PDR, 1998; Vongkhamsao et al., 2022).

To achieve these goals, the Government has established permanent settlements for upland families practicing shifting cultivation and protection of watersheds of streams and rivers that run through the country by rehabilitation and protection of the forests situated in the watershed basins and sources, and by the reforestation of the eroded areas. Government policies encourage planting of teak in shifting cultivation areas by providing ownership of land and supplying teak seedlings at subsidized prices. Current demand by farmers to establish teak plantations is quite high. The overall target is to rehabilitate, conserve and regenerate 17 million ha of degraded forest lands so as to bring 70% of land area of the country under forest cover. Part of the degraded forest lands are to be used for agro-forestry and for other forest oriented development (DoF Lao PDR, 1998; Vongkhamsao et al., 2022).

Harvesting in natural forests is banned since 1989 and elsewhere it is carried out by the State Forest Enterprise, confined largely to the removal of old logs from harvestings carried out in the past, and any fresh felling that may have been undertaken for shifting cultivation. There is a ban on export of logs from the country though there are still problems in the effective implementation of the ban. A Teak Improvement Center is established dealing with selection and propagation of plus trees and clonal seed orchards (DoF Lao PDR, 1998; Vongkhamsao et al., 2022).

These policy measures, combined with expanding road network and easier access to credit up to 60% of the estimated value of plantation, have led to teak being successfully raised over considerable extent of hill lands in Luang Prabang province in northern Lao. However, one clear outcome of this household centric approach in Lao PDR is the conversion of community centric shifting cultivation covering large sized community owned hillsides to individually held small sized teak plantations that are, in practice, no different from smallholder teak plantations elsewhere in the region (DoF Lao PDR, 1998; Vongkhamsao et al., 2022).

(iii) Myanmar

Almost all forests in the country are owned by the government except some community forests that have been accorded ownership under a long term lease agreement with the government. Forest cover in Myanmar has been decreasing continuously and sharply over the past three decades with 56% of the total land area under forest cover in 1990 reduced to 52.1% in 2000 and 50.2% in 2005. Even faster has been the loss of important tree species, teak above all, of bigger sizes from these forests. The Growing Stock (GS) of ten economically important species constituting the bulk of overall composition of forests dropped dramatically from 1340.05 million m^3 (47.81% of total GS) to just 559.62 million m^3 (19.51% of total GS) between 1990 to 2000 with only limited relief in the years that followed (Htun, 2009).

Excessive illicit export to China and, to a lesser extent, to India and Thailand as round or sawn timber, and to European Union and USA as finished products, has been largely responsible for this situation. There are also reports of increased illegal logging of natural teak in Myanmar close to its borders with Thailand. In 1988 the Myanmar government opened its forests to foreign companies for harvesting wood from the forests and transport it back to their country of domicile with the state-run Myanma Timber Enterprise (MTE) granted the authority to regulate logging by the newly emerging private sector largely foreign-owned (Mahadevan, 2021).

But within a short period of the grant of these concessions in Myanmar, Thailand banned teak harvesting in their natural forests. This had the effect of hugely increasing the commercial value of the concessions in Myanmar and a number of Thai firms rushed to obtain logging concessions. Thai timber companies not only bought wood from the MTE but were also subcontracted by the MTE to carry out harvesting and transport of timber in the Myanmar's forests for themselves. The only restriction was that they could not carry out the trade within the Myanmar territory (Mahadevan, 2021).

In Myanmar teak harvesting is carried out under the Myanmar Selection System with both allowable annual harvest and marking of harvestable trees being done by the Forest Department while the actual act of tree felling, conversion and transport to depots, and sale, is conducted by the sole authorized government agency, the Myanmar Timber Enterprises (MTE). This is supposed to grant greater control over timber harvest and trade to the government and thus limit wrongdoings but, in practice, the MTE gets most of its harvesting activities done by sub-contractors as its own personnel and infrastructural capacities to carry out timber harvesting and trade across the length and breadth of the country are very limited (Mahadevan, 2021; Htun, 2009).

At the policy level, the Government of Myanmar has undertaken several steps to restore the forest cover in the country of which raising tree plantations for commercial purposes, local and industrial use has seen noteworthy progress. Restoration efforts have also been focused around watersheds and for meeting domestic fuel and small timber requirements.

(iv) Cambodia

Cambodia does not have natural teak forests and has been encouraging the establishment of teak plantations in the private sector as feedstock to their wood based industries for making finished products for the huge Chinese market next door. Teak was introduced to Cambodia in 1936 in Han Chey commune, Kampong Cham province, as an agro-forestry system by the French colonial administration and subsequently extended to other provinces such as Pursat and Ratanakiri Province. Between 1960s to 1980s the civil war interrupted all afforestation activities, and since 1990s the afforestation in Cambodia has been resumed. In 1993, teak plantations were established at Tuek Chhar over more than 60 ha of land, and at Tboung Khmum over about 300 ha. Subsequently teak has been planted along the national highway in Chlong district of Kratie province and near Ratanakiri province (Chheang, 2022).

The rapid increase in teak plantations in Cambodia over the last two couple of decades is primarily on account of investments by private sector and, to a lesser extent, by smallholders encouraged by government campaigns, and distribution of teak seedlings by local forest administrations to local communities for planting as tree plantations and in agroforestry. Some private teak plantation companies have also been able to get large economic land concessions (ELC) from the government for raising these plantations like 4848 ha to Grandis Timber Limited in 2014, and 350 ha to Teak Farm, an Israeli Company, in 2018 (Chheang, 2022).

A major problem faced by potential investors in teak plantations in Cambodia is the lack of financing at reasonable interest rates as is available to agriculture and horticulture sectors. Teak plantation needs substantial financial investment, especially in the first few years for establishing teak plantation, maintenance and preventative fire protection measures. Uncertain economic returns and frequent market fluctuations discourage Micro Finance

Institutions (MFIs) from extending loans to investors in teak plantations (Chheang, 2022).

Even though there are no specific incentives for investments in teak plantations there are a number of enabling policies and regulations that serve to promote the establishment of private tree plantations in Cambodia in the form of laws, sub-decrees and regulations that include royalty exemption, export tax reduction, and other taxes and fees. Export of timber in log form has been banned to promote domestic wood based industry (Chheang, 2022).

To encourage the establishment of large-scale plantations the Royal Government of Cambodia had issued a Sub-decree on Economic Land Concessions under the Land Law of 2001 providing the criteria, procedures, mechanisms and institutional arrangements for initiating and granting new economic land concessions, for monitoring the performance of all economic land concession contracts, and for reviewing the concessions granted earlier. Economic land concessions are granted to grow food and agro-industry crops including tree plantation, among other important national objectives (Chheang, 2022).

The Forestry Administration is working with the objective to create an enabling environment conducive to develop multipurpose plantation forestry with potential to supply domestic timber needs, increase incomes of local communities, and improve the environment through watershed protection and erosion control. These plantations will be developed to meet current and future market demands, taking cognizance of the need to protect the environment. Species considered include *Dipterocarpus alatus*, *Hopea odorata*, *Azadirachta indica*, *Eucalyptus camaldulensis*, *Acacia auriculifomis*, *Acacia mangium*, and *Sesbania grandiflora* (Chheang, 2022).

The Royal Government of Cambodia has set 50% forest cover, sustainable management of all types of forests, halting deforestation, restoring degraded forests, and promotion of afforestation and reforestation as the national target in the Framework for Cambodian Sustainable Development Goals. Under the Agricultural Strategic Development Plan (ASDP) 2019-2023, the Forestry Administration has set a target of establishment of at least 10,000 ha of forest plantations annually, of which 9,000 ha would be by the private sector. It also plans to distribute 10 million tree seedlings per year under its Conservation of Genetic Resources from Forest and Establishment of Seed Sources for Planting Program. In pursuit of this ambitious goal, the Forestry Administration has identified degraded forests and other degraded lands that are available for restoration and introduced initiatives for investing in the establishment of private forest plantations on state land by forging partnerships between various private sector entities. The Declaration on Tree Plantation Development of 2017 facilitates the registration of private forests established on such lands (Chheang, 2022).

(v) Vietnam

Teak, introduced to Vietnam only in early 20th century, has high adaptation to a wide range of climate condition from the North to the South in Vietnam even though it is not native to the country. It has been planted mainly as a monoculture plantation and only occasionally as mixed species plantation. Teak as the main tree in agroforestry models has been more successful. In northwest and central highlands of Vietnam where teak has been planted as a shade tree for coffee, plum or as intercrop with maize and upland rice it has provided significant benefits by way of wind breaks and additional income from timber after about 20 years. The productivity of teak in Vietnam ranged 7-16 m3/ha/year across different ecological conditions and economic returns from teak plantations are significantly higher compared to those of short rotation species such as acacia and eucalypt (Trieu et al., 2022).

Major challenges for greater acceptance of teak by smallholders in Vietnam are its long harvesting rotation and lack of availability of high quality planting stock. For smallholders who cannot afford to invest in long-rotation crops, teak based agro-forestry is a potential model which can help them earn significant incomes in the years before harvesting. Although teak timber value is much higher than acacia and eucalypt timber in Vietnam, the value chain of teak timber in Vietnam is still disadvantaged in comparison with acacia and eucalypt timber (Trieu et al., 2022).

In recent year, growers have been encouraged by the Government to produce large dimension timber. The price of teak timber is increasing because of shortage of large size timber supply in Vietnam. The forest owners have already started using species other than acacia and eucalypt for their plantation, including teak and some native tree species. Teak promises to be a valuable and suitable tree species for large dimension timber plantation regime in Vietnam. Major challenges for developing teak plantation in Vietnam include lack of capital resource of the growers and its long rotation. This is especially so with smallholder forest owners who currently manage approximately 70% plantation area in Vietnam with average of 2-3ha per household and cannot afford to invest in long-rotation crops and also need to earn significant incomes in the years before harvesting. Although teak timber value is much higher than acacia and eucalypt timber in Vietnam, the value chain of teak timber in Vietnam is still disadvantaged in comparison with acacia and eucalypt timber (Trieu et al., 2022).

Future of Teak Trade Lies in Teak Plantations

With rapid eradication of poverty in large highly populated developing countries like China, India, Brazil, Nigeria, and Ghana among scores of others, and rising incomes, the demand for teak products is increasing across the world. But, at the same time, natural teak forests of India, Thailand and Lao PDR are closed to harvesting, and the only other country with natural teak forests, Myanmar, having lost a very large part of its natural teak resources to unsustainably heavy removals, the only way the burgeoning demand can be met is by planting teak across the tropics. Some work by way of raising teak plantations across 70 countries spread over nearly all tropical regions has been done but that cannot keep up with the demand resulting in sharp and incessant increases in illegal removals of teak from its natural habitats.

Governments in all countries of the Mekong region encourage teak planting by government forest departments over public lands and also incentivize people and communities to establish teak plantations. As the availability of public lands for raising teak plantations are limited everywhere due both to ecological constraints and competing demands for other uses, the trend is to encourage raising teak plantations over private lands by individuals, communities and companies through subsidies and other incentives. But much work remains to be done in this direction since there are still a host of policies and laws in all the countries of the region that, in one way or the other, act to discourage private sector investment in teak foremost of which are the restrictions on felling and transport of teak that were put in place for protecting teak in natural forests and on public lands. Many more roadblocks are offered by a range of land and fiscal policies relating to lease tenures, land conversions from agriculture to tree cultivation, royalties and taxes which are discussed at appropriate places in this paper.

Teak plantations raised across the Mekong region, in terms of the extent of land covered, are both large and small in sizes. Those spread over large extents of land can be roughly classified as Government owned large-scale plantations, private corporate sector owned large scale plantations, individual farmer owned large scale plantations, and community owned cooperative large scale plantations. Small scale plantations, on the other hand, are almost exclusively owned by individuals, both by agriculturists on a part of their cultivated lands, and by smallholders primarily engaged in some non-agriculture economic activity in a distant place and raising these plantations on small plots of lands held by them in their ancestral villages.

Major Concerns of Large-scale Teak Plantations are Ecological Aspects.

Most common of large sized teak plantations in the Mekong region are those raised by government forest departments though a few large sized plantations have also been raised by companies and individuals holding or acquiring large chunks of lands specifically for this purpose. The major concern of large scale teak plantations is ecological in nature. Most lands available to the government forest departments for raising large scale plantations in the tropics are those that have been partially or severely degraded in the past. And tropical forest plantation projects, even apart from those raised under forest landscape restoration programs, funded through national budgets or financed by international development agencies are designed to provide a range of secondary social, ecological and environmental benefits in addition to timber.

Trees promote various processes linked to species diversity promoting colonization of the understory by altering the chemical, physical and biotic soil quality through root penetration and decomposition, soil biota activity, shading, increasing humidity and reducing temperatures. Trees provide perching places for birds and bats dispersing seeds, and an environment for small arboreal and ground-living and digging animals including invertebrates, pollinating, spreading and burying seeds. Grasses, and hence fires, and exotic weeds are suppressed by shading from the trees (Udayana et al., 2019; Lamb et al., 2005; Parrotta, 1995).

But teak appears to limit secondary ecological benefits significantly by discouraging the return of many native species - trees, shrubs, herbs and grasses - in teak intensive plantations. Ground flora is particularly affected often leading to loss of top soil in medium to high rainfall localities. It is for this reason that high intensity teak planting is not a preferred watershed protection strategy. Several aspects of teak's biology may contribute to the species' exclusion of native trees (Healey & Gara, 2003). The overall effect on understory vegetation is that of a dynamic balance of the impact of the planted trees on the soil, moisture, microflora and microfauna and this, on balance, discourages understory growth in teak plantations. It is for this reason that large scale forest landscape restoration of degraded forest lands in the Mekong region by government forest departments, with expectations of a quick return to pre-degradation biodiversity rich status, is not likely to be teak-intensive in the years ahead even though teak would always be an important component.

Large scale teak plantations on non-forest lands is a possibility but such lands have many competing uses in developing societies of the region and are difficult to come by. The most likely growers of large scale teak plantations in the region in the coming years would be corporations or rich landowners. Once access to such lands is gained, raising money for planting teak is usually not an insurmountable problem particularly if the planter owns the land and, with adequate finances, both high quality expertise and planting stocks, become available to them. Restrictions on harvesting and on transport and trade impact all plantation owners irrespective of the size and has been discussed elsewhere in this paper.

Smallholder teak planter holds the key

The Lomé Statement for Smallholder Forest Landscape Restoration (FLR) issued at the ITTO Regional Workshop on Promotion of Smallholders Forest Landscape Restoration in West Africa held in November 2019 at Lomé, Togo, notes that smallholders "are most often classified according to their size, which can vary from less than one hectare up to 10 hectares and more. Legally, smallholders can be individuals, family or clan structures, communities, churches or associations. Within the framework of FLR, smallholders include tree planters (woodlots for timber or fuelwood), tree crop producers and farmers who incorporate trees in their farming systems, as well as those who restore and protect remaining natural forests."

What would be considered smallholding will, therefore, be context specific. In the heavily populated Mekong sub-region the per capita land availability is very low ranging from 0.12 ha in Vietnam to 0.34 ha in Thailand. Land holding in the region is typically small with as many as 85% landholding in Vietnam, 38% in Laos, 34% in Myanmar, and 23% in Thailand being less than 1 ha (FAOSTAT). Average size of agriculture landholdings per agriculture household in the Mekong region is 0.7 ha in Vietnam, 1.6 ha in Laos, 2.4 ha in Cambodia, 2.3 ha in Myanmar, and 3.1 ha in Thailand (Ingalls et al., 2018). Given the nature of landholdings it would perhaps be appropriate to consider landholdings upto 2 ha as smallholdings in Vietnam and upto 5 ha in other countries of the region for the purpose of raising tree plantations.

From growing food to growing teak

Shifting cultivation is still being practiced in parts of Lao PDR, Myanmar, and Cambodia where indigenous people live in communities. In Lao PDR the policies on the utilisation and management of natural resources emphasizes the need to reduce shifting cultivation and control deforestation. To achieve these goals the Government has sought to establish permanent habitations for upland families practicing shifting cultivation and protect the watersheds of streams and rivers by rehabilitation and protection of the forests situated in these watersheds and by the reforestation of the eroded areas. These people so settled are allocated forest lands, both degraded and well-forested, to manage and protect on a household basis thereby granting security of land tenure to the rural people and enable transmission of their inheritance to their heir. Government forestry units at all levels are expected to act as the servicing units for the local people and provide technical assistance in extension techniques for farming, forest and fruit tree planting, seed and fertilizer supply (DoF Lao PDR, 1998; Vongkhamsao et al., 2022)

These policy measures, combined with expanding road network and better access to credit, have led to teak being successfully raised over considerable extent of hill lands in Luang Prabang province in northern Lao. However, one clear outcome of this household centric approach in Lao PDR is the conversion of community centric shifting cultivation covering large sized community owned hillsides to individually held small sized teak plantations that are, in practice, no different from smallholder teak plantations elsewhere in the region.

Other countries of the region like Myanmar that still have many communities practicing shifting cultivation may also encourage similar shift away to family owned teak plantations and teak based agroforestry over such lands. However, this will have to be primarily a socio-political decision that would decide whether these countries are willing to hasten the process of conversion of community owned land assets of indigenous hill people, presently accessible to the entire communities on the basis of their needs, into small sized individual family owned assets. This is because this process will also result in fundamental, deepset, social changes at a great pace with consequences for the overall governance of the country.

Policy Support to the Smallholder Teak Planter

Protecting the interests of unorganized and widely dispersed small-scale teak growers is a major challenge before the policy makers. New technologies for planting, improved planting stock, and means to select more suitable sites for planting teak, are now available as are newer provisions for financing under the many international agreements and national mandates on biodiversity, climate change and on limiting pollution. Increased access to marketing of teak products in high end international markets by small growers is also on the horizon. But the reach of the smallholder to all these positive changes is still very limited. In addition, there are a host of existing fiscal, harvest, trade, transport, and land related policies that adversely impact the smallholders. A comprehensive review of all existing practices, policies and regulations is needed to identify specific policies and measures that are most efficient and cost effective in leading to the desired changes at global, national and local levels.

Mapping site quality

Site quality has a dominant role in determining the productivity, and profitability, of teak plantations and, therefore, it is important that the smallholders be guided and encouraged to opt for the best available sites. Presently site quality assessments are based exclusively on growth parameters but increasingly ecological and biodiversity values are also becoming important even for smallholder plantations. This is particularly important if they are to benefit from national and international financing most of which is inclined towards climate change mitigation and adaptation and Sustainable Development Goals. The growth and yield estimates for these sites should, therefore, be prepared in such a manner that the farmer is able to understand the unavoidable moderations in wood yield when ecological goals are also expected to be fulfilled. This will better prepare him for negotiating the prices of these societal and ecological goals with relevant authorities. A network of permanent sample plots covering the entire range of growth and management conditions should be established in the region and improved national tables giving growth and yield estimates in different parts of this range of site and treatment conditions should be prepared and made available to teak growers.

Site management to sustain and enhance productivity may involve changes in silvicultural prescriptions, soil conservation measures and fertilizer application. Existing protocols, where they exist, are inadequate and serve only large government and private plantations. The government forest departments of the region may develop these protocols specifically for smallholder plantations and make them easily accessible to all concerned.

High quality planting stock

Most often smallholders use the planting stock available closest to the planting site and realize their teak crop is of poorer quality only when it is too late to do anything. And resulting low returns on account of low quality and quantity of teak timber produced then deters more smallholders from opting for teak. Sometimes high-quality teak planting stocks are available through large plantation companies but these are high priced and incur considerable costs in transportation or tied to conditions that smallholders are reluctant to agree to. The smallholders expect assured quality of planting stock delivered at reasonable prices at convenient locations.

The forestry departments of the region may produce certified high-quality teak planting stock offering a good range of choices that are well advertised, and make it available through local extension offices of all land related government departments like horticulture, animal husbandry and agriculture departments besides their own outlets. The planting stock should be offered at low prices but not free of cost so as to avoid wastage. Since there are primary schools in the remotest villages it would be useful to engage the services of resident teachers as short term planting material stockholders and extension workers during the planting season.

Photo 25-1 Teak Plus Tree T6 at Karulai in Nilambur South forest division, Kerala, India for producing high quality planting stock (Credit: B Preetha, KFRI, Peechi, India)

Discouraging speculative investments

Expectations of excessive profits can lead to speculative investments on a massive scale. This is what happened in the decades of 1980 and 1990 when there was a surge of investment in teak plantations across the tropical world with experts offering cost-benefit analysis of long rotation plantations suggesting return on investment of 15% assuming low initial investments, no opportunity cost for land, easy marketability of teak wood of all sizes, and continued increase in the prices of teak timber. When these high expectations were not met it led to large scale disappointment and collapse of the so-called teak schemes across the tropical world. Had rigorous cost-benefit analyses been undertaken taking into account the true opportunity cost of the land to the smallholder in addition to the site and environmental conditions, management regimes, and accessibility to markets, this large scale speculative investment based on misleading claims could have been easily avoided.

The government forest departments of the countries of the region should commission universities and research institutions for carrying out rigorous cost-benefit analysis of teak plantations on all likely sites within their countries at different rotations taking into account the true labour costs, and the real opportunity costs of the land under plantation. This will not only give a true picture to potential investors in smallhold teak plantations but also build capacity for quality cost analysis within their countries.

Tenure security and felling permission

Smallholders in some countries of the region, particularly Thailand, have this fear that if they plant trees on their lands they may not be allowed to fell the trees and use the land for agriculture or for house construction at a future date. Thus, while the smallholder continues to be the owner of her land once trees are planted on it, her economic choices related to the land become severely restricted. This is more likely to happen on trees planted on landholdings located on steep slopes, on other ecologically fragile areas, and on places of tourist interest with high expectations of green surroundings.

It needs to be appreciate that the only reason a smallholder plants teak on his land is to maximize his earnings and not for aesthetic purposes or for binding soils, and certainly not for inviting restrictions on his existing freedoms on the enjoyment of his land assets. If such social objectives are to be added to his personal goals in planting teak by the government under extraordinary circumstances for public good then, as a matter of principle, the government must be willing to compensate the smallholder for all the consequential losses incurred by him. In the interest of promoting teak planting by smallholders every country in the region should incorporate this principle in their policies.

Restrictions on transport

Existing policies and legislation in some countries of the region place restrictions on the transport of teak harvested from private lands by farmers. But these restrictions, introduced during colonial times to protect government owned natural forests from illegal felling, act as severe disincentive for smallholders who find it difficult to obtain the required permissions to transport their timber to the sawmills and market and often become victim of corrupt practices. Many states in India that had the same restrictions have now removed them atleast for species that are not found in natural forests in the neighbouring districts which has greatly eased the situation for tree growers. The task of protection of teak in natural forests belonging to the State is a duty of the larger society and of the State, the cost of which should be borne by the State and not by individual smallholders who take to teak growing as a normal economic activity. And now DNA based technologies are also available that can help establish the true source of timber. These technologies needs to be further refined and made easier and quicker which task can be undertaken by countries like Thailand, Malaysia, Indonesia and India that have the technological expertise in the field.

It is strongly recommended that the governments of the countries in the Mekong region may consider removing the restrictions on transport of teak from plantations altogether and instead rely on in-situ protection of their natural teak resources using appropriate technologies.

Attracting investments for smallholder teak plantations

Smallholders find it difficult to source funds for financing investment in their teak plantations on account of the multiple risks involved. Institutional assistance for loan financing for raising teak plantations across the region is inadequate at best and often absent altogether. Loan financing for these long-term investments pose serious problems and currently there are not many instruments that can satisfactorily link the financial institutions providing loans with the teak growers needing loans. And even when there are potential investors willing to risk their capital in such ventures, like the European and American Pension Funds mandated to invest a small part of their portfolios in such green investments, there are no official mechanisms that can link these prospective financiers with genuine smallholder teak growers. It is this gap which needs to be bridged.

The forestry departments of the countries of the region should provide platforms on which genuine smallholder teak growers can be brought in touch with financial institutions mandated and willing to extend loans to smallholder teak plantations and potential green investors. Investment in teak plantations of all sizes should be officially declared as "green investment" and attractive financial and tax incentives provided to promote these investments. The tax incentives can also be linked to the length of rotation which would help encourage the growing of larger sized teak timber.

Tax Relief

As the availability of public lands for raising teak plantations are limited everywhere due both to ecological constraints and competing demands for other uses, the trend is to encourage raising teak plantations over private lands by individuals, communities and companies through subsidies and other incentives. In India the income accrued from agriculture is exempted from income tax without any upper limit and, since tree growing is considered agricultural activity, there is no income tax on the sale of trees harvested. This is a major attraction for tree growers and is worthy of emulation.

Another area in which tax relief could help fledgling teak wood industry, and thereby encourage planting of teak as source of raw material, is sawing and making furniture and other consumer products. This could be done by way of a sharp reduction in taxes on the existing industry and a complete tax holiday for 5 years for new industries. And, in order to ensure that this helps create rural employment, such relief may be limited to only rural areas.

Support under UNFCCC mechanisms

Teak forests in their natural zone provide a range of ecosystem services that are highly valuable for the welfare of larger global and national societies including mitigation of, and adaptation to, climate change. The forest departments and other authorities in the Mekong sub-region have long been discussing about additional incomes for community and individual tree planters by way of carbon credits for mitigating climate change through carbon sequestration, and through other ecological services that the forests and tree plantations render to the society. Teak growers across the region expect their governments to enact policies and take steps that enable them to financially benefit from these new possibilities.

The very rigid eligibility conditions of the Clean Development Mechanism (CDM) under the Kyoto Protocol, the excessive technical complexities, and very high transactional costs, in implementing CDM projects placed the smallholder teak plantations outside the reach of this facility. REDD+, which stands for reducing emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests, and enhancement of forest carbon stocks, addresses a part of the limitations of the CDM but REDD+ is essentially meant for national or sub-national level efforts where the achievements in sequestering carbon have to be measured against the national or subnational baselines. This means that till a country, or atleast a significantly sized region within it, is prepared and ready for REDD+ the communities and smallholding teak growers would not be able to access financial benefits from the climate change mitigation services they provide to the world.

Article 6 of the Paris Agreement on Climate Change has provisions for both market and non-market mechanisms in support of climate change mitigation and adaptation activities that need to be utilized creatively to finance smallholder teak plantations. The recently held COP26 at Glasgow in Nov 2021 had made much progress in finalizing rules for operationalizing these mechanisms in practice and some more guidelines are expected to be finalized by the subsidiary bodies of the UNFCCC in June 2022 following which ITTO may commission a small pilot activity to test ways to use these Article 6 mechanisms in support of the smallholder teak plantations.

The forest departments of the countries of the region should explore the possibility of creating provisions for pooling the smallholder plantations into larger sized carbon sequestration schemes like REDD+ and other schemes that enable payment for ecological services rendered by these tree plantations. The country negotiators in UNFCCC, UNCCD and CBD Conferences of Parties should be asked to bring these concerns into international negotiations.

Marketing short rotation timber

Smallholders invariably opt for short rotation and for them even twenty years could be a long rotation. Investors in large teak plantations also expect interim incomes from small-diameter wood obtained from thinnings. But the higher proportion of sapwood in short rotation teak brings in changes in physical and mechanical properties, and the appearance, of the wood in comparison with larger diameter wood. This lowers their market value. Processing of smaller dimensions. Difficulties in processing and marketing smaller dimensions also deters small growers.

Some countries, however, appeared to have found solution to this problem. In Java, Indonesia, demand for small sized teak has evolved over time with improvements in utilization technologies thereby facilitating the use of smaller dimensions. In recent years, teak has been harvested in as short a time as 8 years in places where small sized teak fetches good value in the market. The current and potential uses of small dimension plantation wood from teak plantations should now be assessed recognizing these dynamic changes.

For hastening this process of market acceptance of small sized teak from short rotation plantations the governments and forest departments of the countries in the region should promote the use of small timber utilization technologies that are already in use in Indonesia and elsewhere and also encourage further innovations through financial and logistical support measures. Chemical treatment of higher sapwood timber can impart it greater strength, longevity, and protection against insect attack. Specific time bound projects should be awarded to universities to conduct research on these subjects.

Also, in order to facilitate comparisons between teakwood of different sizes and localities, common standards, definitions and nomenclature need to be adopted across the teak producing countries. This is a very big task not within the capacity of producing countries in the Mekong region but it can begin here as an ITTO project with the ultimate objective of making the standards evolved acceptable all over the world. This project should entail review of existing national grading systems for teak timber, taking into account the quality and dimensions obtainable from shorter rotation plantations in end harvest as well as thinnings. International collaboration between teak producing and consuming countries is also required on products and markets and for standardization of definitions in relation to technology, markets and sizes. Such collaboration is particularly relevant for the standardization of grading rules for teak timber and for carrying out research on demand, supply and prices of varying grades of teak.

On pruning, thinning, and girdling before harvest

Pruning is typically required to maximise the production of high-quality teak timber. It is best to prune young teak up to 50% of the tree total height at the first thinning. The first pruning should be carried out when the stand reaches the height of 4–5 meters, second pruning at 9–10 meters and the last pruning should be done when the stand reaches 12 meters height.

Thinning is an important tool for ensuring high quality and higher volume product at the end of rotation. It results in improved growth and yield of stands as well as individual tree sizes and tends to have positive effects on stem form. But many small growers use it to remove best quality trees years before the rotation period which results in reduction in both quality and quantity of the timber produced at the end of rotation.

The extension wings of the forest departments of the region may hold regular workshops in localities that have large number of teak plantations to demonstrate best thinning and pruning practices. The final decision on thinning, however, must be left to the teak growers because sometimes their immediate need of money may be more important to them than the returns that may come at the end of rotation.

Girdling trees well before harvest at rotation age has been an age old practice in Myanmar that makes the tree loose sap and get seasoned ready for immediate use as timber. But this also results in loosing growth that would have occurred during the period between girdling and harvest which is important in short rotation plantations. If girdling is done in summers just three months before harvest at 20-year rotation the loss in growth may be insignificant but the possibility of immediate use may enhance its commercial value considerably. The forest departments of the region may examine this closely in different localities and seasons and advise the smallholder teak growers in the neighbourhood accordingly.

On harvesting teak in natural forests

Harvesting of teak in natural forests is banned in Thailand since 1989 where most of these natural forests have been declared Protected Areas. Teak harvesting in natural forests of Lao PDR is also prohibited since 1989 though considerable quantities of naturally grown teak still enters markets which is said to be coming from shifting cultivation areas of north-western uplands of the country and from left over teak logs harvested in the past.

Photo 25-2 Natural teak forests at Sungam, Parambikulam, Kerala, India
(Credit: P K Thulasidas, KFRI, Peechi, India)

In Myanmar teak harvesting in natural forests is carried out under the Myanmar Selection System with both assessment of allowable annual harvest, and marking of harvestable trees, being done by the Forest Department while the actual act of tree felling, conversion and transport to depots, and sale, is conducted by the sole authorized government agency, the Myanmar Timber Enterprises.

While this has promoted teak plantation activities within Thailand and also in neighboring Cambodia, Laos and Vietnam it has also led to increased demand for teak harvesting in natural teak forests of Myanmar where restrictions on natural teak harvesting are limited by the principles of sustainable forest management. There are also reports of increased illegal logging of natural teak in Myanmar close to its borders with Thailand.

While the total ban on teak felling in natural forests everywhere is often lauded as a very effective approach to conservation of this great gift of nature, in the opinion of this author the benefits are overvalued and the outcomes are not without great risks. The increased risks are in having precious natural forests with large number of old, and often diseased and decaying trees, that become host to very huge infestations of *Hyblaea puera*, a leaf defoliator commonly found on teak, and other local pests that then damage younger crop. Even worse, during drought season these old decaying trees greatly increase the risk of crown fire spreading across the teak forests as they provide plentiful standing fuel to the fires. Also in National Parks and other Protected Areas with natural teak forests too high a density of teak trees discourage grass growth on the forest floor reducing the carrying capacity for wild ungulates which in turn affects the populations of predators. So a regular but moderate selection felling of old, dead and dying teak trees is advisable in these forests.

Containing environmental damage and human injuries during harvesting

Harvesting and extraction operations are the forestry activities that generally cause the most significant impact on the environment. This impact can be reduced through proper planning and control of harvesting operations using sound principles, systems, and techniques that have stood the test of time. Successful harvesting should be (a) technically feasible considering physical limitations, engineering knowledge, and environmental relationship of the forest, (b) economically viable considering the costs and benefit of short and long range consequences, (c) environmentally sound considering impacts on the natural and social environment, and (d) institutionally feasible considering laws and regulations, landowner objectives, and social values.

The most common cause of accidents during harvesting is the lack of knowledge and necessary skills among the workers and repeated training, and effective supervision, is thus the most effective tools for reducing risks. Wearing suitable Personal Protective Equipments provides protection when all other control measures cannot adequately eliminate or minimize risks to a worker's health and safety.

The extension wings of the forestry departments of the region should conduct annual workshops in each important teak plantation district to communicate with the teak growers on the best harvesting practices.

On certification

There is increasing demand from EU and North American countries for certification of timber exported to their countries in raw or processed form. And since the economies of the Mekong region rely to a considerable degree on their exports there is pressure on the teak producers to get their timber certified. Higher prices in niche markets, where consumers are prepared to pay a premium price for teak obtained from sustainably managed areas, are an incentive to produce certified timber. But the costs of complying with the environmental standards required in certification process are quite high and almost always prohibitive for smallholders. And also the niche markets willing to pay higher prices for certified timber may not actually be the target market for most small growers. It would be quite a while before a clear consumer preference for certified timber emerges in a widespread market for timber and its products.

The choice to go for certification or not is best left to the teak grower. But for this choice to have any real meaning there should first be easily accessible, and internationally acceptable, certifiers within their physical and economical reach. In this the ITTO can play a role by helping set up an autonomous independent certification body for the Mekong region on the lines of international certifiers like the Forest Stewardship Council (FSC).

Illicit felling and theft of teak

Illegal felling of valuable teak trees by miscreants is a major concern of smallholders particularly those whose lands are located in remote sites away from the watchful eyes of villagers. They are not able to engage the services of plantation watchers as big plantations do because of the high cost of individual plantation watchers. The smallholders expect a reasonable degree of protection of their standing assets as an important duty of the State.

The forest departments of the countries of the region may identify hotspots of theft and organize villagers to combat the problem in these areas. Selected villagers can also be given, after due training and under competent supervision, the legal powers of a forest official to book offences against the culprits. But this has to be done with great care and under close supervision otherwise it has the potential of creating conflicts within village communities.

Reducing losses by fires, diseases and insect attacks

The smallholders are able to deal with the fires, diseases and insect attacks on their teak trees located within agricultural fields close to the habitations but oftentimes find their plantations located adjacent to the government forests exposed to fires that originate within forests and cannot be controlled by outside efforts. Less frequently, they face similar problems with tree diseases and insect attacks, too, that originate within adjacent large sized government forests. A clear expectation of the smallholders is that reducing these losses is the responsibility of the State.

While these expectations of the smallholders cannot be fully satisfied by the governments of the region because it would encourage tendencies to turn private responsibilities into public duties there can be little doubt that government policies should actively prevent the escape of fires, and insects and pests, from government forests to the adjacent teak plantations by smallholders. Prevention of escape of fires and of plant diseases and insect attacks from government forests to adjacent plantations of smallholders must be accepted as a public duty and a protocol for taking adequate and timely steps must be developed in consultation with smallholders and followed strictly. For this purpose well managed firelines, cleared of all vegetation and debris, along the boundaries between fireprone government forests and smallholder teak plantations would reduce the chances of fires, diseases and insects spreading outwards. It must, however, be made clear that the protocol does not lessen the duty of the smallholder towards the protection of his own land and crops growing there.

The way forward

There are several areas related to teak and its planting by smallholders for economic purposes that need to be explored thoroughly to enable governments to lay down appropriate policies to promote this economic activity over larger extents of lands suitable for growing teak in the countries of the region. In the paragraphs below the more important of these have been described briefly.

An important area for research is the impact of complete ban on teak felling in natural forests and Protected Areas, including thinnings that were planned earlier, on the quality of habitat for wild animals by way of availability of ground flora as feedstock for herbivores, effect on water sources, frequency and intensity of forest fires, and on the socio-economic conditions of the indigenous people residing inside and in close vicinity of these forests. The universities in the region should be encouraged by the country governments and the ITTO to undertake several independent research projects on different sites so that a truer picture may emerge of the realities on the ground which can then be utilized to review the ban on teak felling in natural forests.

There are unsubstantiated claims of teak plantations having a deleterious effect on the productivity of agricultural lands downstream and even on the site quality of forests below. These needs deeper investigations by forestry universities and research institutions in collaboration with agricultural universities and quick dissemination of the outcomes as they emerge. Research is also recommended on biological control of pests and diseases that are common in teak plantations in the region in order to facilitate large scale application of these measures by smallholders. and to overcome resistance. Raising mixed plantations instead of pure teak plantations may also help control the spread of infestations but this needs to be established by data based research. Integrated pest management models that are effective as well as economical need to be designed.

Intensively managed plantations requiring continuous care have the potential to provide considerable employment and income to the rural economy and thereby provide a crucial public good which needs to be acknowledged in policies and appropriately compensated through tax relief or subsidies. Very few studies have, however, been carried out on the socio-economic benefits of teak plantations. The country governments of the Mekong region should, with the help of bilateral or multilateral international financing agencies, commission universities and research institutions in their countries to undertake such studies. The outcome of these studies can help decide the quantum of compensation or relief to the smallholder teak planters for the services rendered to the Society.

There is need to strengthen international collaboration in *ex-situ* conservation for provenance identification and testing, and formulation of common methodologies and procedures to allow comparison of results across countries. Collaborative efforts at the regional and global levels are particularly important for testing clones in a variety of sites and under diverse conditions and for developing technical guidelines for the exchange of genetic materials. National efforts to collect growth and yield data could be complemented through a network of permanent sample plots. The conservation of teak genetic resources and the monitoring and control of transboundary pests and diseases are other important areas for collaboration.

Obtaining prices for teak logs and sawn timber is difficult because no common international log grading rules have been established, most exporting countries' definition of log dimensions as well as measuring units are different. Teak prices are very closely related to wood quality which is determined by dimension, bole shape in terms of roundness and straightness, heartwood-sapwood ratio, regularity of annual rings, number of knots, colour, texture and the soundness of the butt log. Teak from natural forests sells at comparatively high prices as teak harvested from plantations is typically smaller in size and rarely reaches the dimensions and quality that fetches the best prices.

The ITTO is best placed to facilitate this kind of collaboration by bringing two or three forestry universities of the region work on a collaborative project of this nature with institutions in Japan, South Korea, Australia, India and other countries that have the requisite technological know-how. The fact that the countries named above have existing bilateral agreements of cooperation and assistance in the field of environment and forests with most countries in the Mekong region will help in joint financing of such a project.

Acknowledgement

I am indebted to Dr Hwan Ok Ma, Prof Yongyut Trisurat, and many learned scholars, forest practitioners and scientists who presented their ideas during the scores of physical and online workshops organized across the countries of the Mekong region under this project. I am particularly thankful to Dr Thomas Enters for several ideas encapsulated in his article titled "Site, technology and productivity of teak plantations in Southeast Asia" published in Unasylva 51(201):55-61. I also owe thanks to Dr Nopparat Kaakkurivaara for the insights she provided in her many presentations on teak harvesting in the Mekong region.

References

Barton, G. & Bennett, B. (2010). Forestry as Foreign Policy: Anglo-Siamese Relations and the Origins of Britain's Informal Empire in the Teak Forests of Northern Siam, 1883-1925. *Itinerario - European Journal of Overseas History,* 34(02), 65 - 86.

Barton, G. A. (2002). *Empire Forestry and the Origins of Environmentalism*. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9780511493621

Chheang, D. (2022). *Teak plantations in Cambodia*. Accepted for publication in the IITO Book on Teak in the Mekong Region. Kasetsart University, Bangkok; ITTO, Yokohama, Japan; and TEAKNET, Kerela, India.

DoF Lao PDR. (1998). *Teak in the Lao People's Democratic Republic*. Published in "Teak for the Future - Proceedings of the Second Regional Seminar on Teak", RAP Publication: 1998/5, FAO Regional Office for Asia and the Pacific (RAP), Bangkok, Thailand. https://www.fao.org/3/ac773e/ac773e0h.htm

Enters, T. (2000). Site, technology and productivity of teak plantations in Southeast Asia. *Unasylva,* 51(201), 55-61.

FAO. (2009). *The Future of Teak and the High-Grade Tropical Hardwood Sector*. Planted Forests and Trees Working Paper FP/44E. Accessed on http://www.fao.org/docrep/012/k6549e/k6549e00.pdf

Handel, D. (2012). *Into the Woods*. Cabinet magazine, Issue 48/Trees, cabinetmagazine.org, 2012.

Healey, S. P. & Gara, R. I. (2003). The effect of a Teak (*Tectona grandis*) plantation on the establishment of native species in an abandoned pasture in Costa Rica. *Forest Ecology and Management,* 176(1-3), 497-50.

Htun, K. (2009). *Myanmar Forestry Outlook Study*. Asia-Pacific forestry sector outlook study II. Working Paper Series, Working Paper No. APFSOS II/WP/2009/07. Food and Agriculture Organization of the United Nations, Regional Office for Asia the Pacific, Bangkok, Thailand.

Ingalls, M. L., Diepart, J.C., Truong, N., Hayward, D., Neil, T., Phomphakdy, C. et al. (2018). *State of Land in the Mekong Region*. Centre for Development and Environment, University of Bern and Mekong Region Land Governance. Bern, Switzerland and Vientiane, Lao PDR, with Bern Open Publishing.

Lamb, D., Erskine, P. D., & Parrotta, J. A. (2005). Restoration of degraded tropical forest landscapes. *Science,* 310(5754), 1628–1632.

Mahadevan, P. (2021). *Myanmar's Illicit Timber: Flows, drivers and actors*. Research Report, Global Initiative Against Transnational Organised Crime, Octoter 2021.

Parrotta, J. A. (1995). Influence of overstory composition on understory colonization by native species in plantations on a degraded tropical site. *Journal of Vegetation Science, 6*(5), 627-636.

RGoT (2015). FOREST PLANTATION ACT (NO. 2), B.E. 2558 (2015), Office of the Council of State of Thailand. http://web.krisdika.go.th/data//document/ext809/809909_0001.pdf

Stebbing, E. P. (1947). The Teak Forests of Burma. *Nature, 160*(4076), 818-820.

Stebbings, E. P. (1922*). The Forests of India Vol. 1*. John Lane The Bodley Head Limited, London, UK.

Sumantakul, V. & Sangkul, S. (1998). Teak resources in Thailand. In: *Teak for the future – Proceedings of the Second Regional Seminar on Teak*. (eds M. Kashio & K. White). RAP Publication 5, TEAKNET Publication 1. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.

Tarling, N. (1993). *The Cambridge history of Southeast Asia*. Cambridge University Press, Cambridge, UK.

Trieu, D. D., Tran L. D. & Nguyen V. B. (2022). *Teak plantations in Vietnam*. Accepted for publication in the IITO Book on Teak in the Mekong Region. Kasetsart University, Bangkok; ITTO, Yokohama, Japan; and TEAKNET, Kerela, India.

Udayana, C., Andreassen, H. P. & Skarpe, C. (2019). Understory diversity and composition after planting of teak and mahogany in Yogyakarta, Indonesia, *Journal of Sustainable Forestry, 39*(5), 494-510

Vongkhamsao, V., Inthilathi, B. & Chaleunsauki, B. (2022). *Natural teak Forests and Plantations in Lao PDR*. Accepted for publication in the in the IITO Book on Teak in the Mekong Region, Kasetsart University, Bangkok; ITTO, Yokohama, Japan; and TEAKNET, Kerela, India.

Chapter 26: Knowledge Management for Teak: The International Teak Information Network (TEAKNET)

P.K. Thulasidas and M.P. Sreelakshmy

Abstract

For 25 years TEAKNET has always been in the forefront of international efforts to bring together numerous stakeholders under its umbrella and facilitates transfer of knowledge and dissemination of information to promote collaborative efforts for the sustainable development of teak sector including smallholder forest industry and trade. It serves as a dialogue platform among the tree growers/planters, traders and researchers on problems in teak sector and suggest solutions. Being a non-profit, non-governmental organisation set up by FAO of United Nations way back in 1995, it is the only R & D network organisation in the world exclusively dedicated for the information dissemination of a single species of teak. Teaknet collaborated with FAO, ITTO, IUFRO and other agencies in organising many meetings/partner events/ WTC's and was a project partner in the global teak study report published by IUFRO in 2017. In the on-going ITTO executed teak project in Mekong sub-region, Teaknet plays a significant role in knowledge management and networking in the GMS region and beyond. The success stories presented in this document briefly explains the network activities it had undertaken and advocated transparency in the international trade of teak and spread the message of regional/international cooperation in the sustainable utlisation of teak resources and teakwood value chains.

Introduction

Teak is one of the most important and valuable hardwoods in the world, and planted teak forests have attracted large-scale private sector investments in Africa, Asia and Latin America. About 95% of the natural teak forests and 83% of planted teak forests are confined to the Asia-Pacific region. The area of natural teak forests growing in only four countries (India, Lao PDR, Myanmar, and Thailand) is on continuous decline for the last couple of decades as per the latest FAO and IUFRO reports (Kollert & Cherubini, 2012; Kollert & Kleine, 2017) due to various anthropogenic disturbances and overexploitation that ultimately threatens the natural gene pool. According to the report "State of the World's Forest Genetic Resources" (FAO, 2014) teak remains at the top of the list of tree species that are considered in many tropical countries as a national priority for the conservation and management of forest genetic resources. As for planted forests, teak is the only hardwood species that has been grown increasingly in about 70 tropical countries. Owing to the high quality of teakwood, the increasing demand in the international market, the adaptability to varied tropical climates for easy cultivation, and the comparatively short rotation periods of 20-25 years that allow for the production of good quality timber, make teak one of the most preferred timbers traded internationally.

The Origin of TEAKNET

Recognizing the importance of teak and the lack of a common platform to share the multifaceted problems faced by planters and investors dealing with teak cultivation and management of natural and planted teak forests, the FAO of the United Nations proposed the establishment of an Asia-Pacific Network on Research and Development of Teak (TEAKNET) at the first regional seminar on teak held in Guangzhou, China in early 1991. The proposal was executed in 1995 at the 2nd Regional Teak Seminar in

Yangon, Myanmar. Thus, TEAKNET was officially established, and it operated in Yangon until 2007.Later by a decision of the Steering Committee of TEAKNET coinciding with the ITTO sponsored Regional Teak Workshop held in Kerala Forest Research Institute (KFRI), Kerala, India during 2007, relocated the Secretariat to KFRI for operational reasons. KFRI was chosen because of its long standing tradition of three decades of teak related research and a core group of committed scientists with clear understanding of the key issues on the subject and the ability to provide technical support to the network.FAO Regional Office for Asia-Pacific, Bangkok (FAO-RAP) helped to formulate a detailed working plan for the network mechanism, including the administrative and operational framework, financial implications and representations of member organisations. Concurrently, from 1996-97 IUFRO also established a special working party on the "Utilisation of Planted Teak" in its Division 5 (Forests Products) which aims at research and dissemination of scientific information on teak timber produced within the framework of socially and environmentally acceptable norms of sustainable forest management. Both these networks of TEAKNET and IUFRO`s teakwood working party are non-profit, non-governmental organisations working in parallel with the main objective of information sharing on research and development of teak and its sustainable utilisation.

Objectives of TEAKNET

As in the case of other networks like the Asia-Pacific Forest Genetic Resources Program (APFORGEN), Asia-Pacific Forest Invasive Species Network (APFISN) the primary objective of TEAKNET is to facilitate exchange of information and to promote collaborative efforts to deal with the common problems faced by the teak sector and suggest solutions. TEAKNET is the only R & D network organisation in the world exclusively dedicated for the information dissemination of a single species, teak. The major objectives envisaged, among other things are:

i. To link and strengthen international network for national, regional and international institutions / organisations working on teak.

ii. To serve as a dialogue platform among the tree growers/planters, traders and researchers on problems in teak sector and find solutions.

iii. To facilitate transfer of knowledge and dissemination of information on all aspects of production and marketing of teakwood, including market information and price trends through its website www.teaknet.org

iv. To promote collaborative studies on critical areas of mutual interest in the development of teak sector, including quality assessment of short rotation teak, unification of log grading rules, tracing the geographical origin of teak logs to prevent illegal logging and for sustainable wood supply chains.

v. To develop online databases and decision support tools beneficial to stakeholders of teak sector and the updated teak bibliography made available online to the members.

vi. To publish periodical reports/information bulletins and organize periodic conferences/ workshops/meetings for the development of teak sector and formulate policy guidelines to be shared among the national governments, including matters related to development of timber certification and carbon credits.

vii. To facilitate the exchange of genetic materials (superior seed sources/improved planting materials) to enhance productivity of teak plantations/ smallholder farmer's teak, subject to the respective country regulations.

Organisational Structure of TEAKNET

The success and strength of the Teaknet is critically dependent on its ability to allure supporting members and the wider participation by national and international

organizations and institutions that are concerned with the conservation, management and utilisation of teak. Figure 26-1 shows the simplified organigram of TEAKNET. The network is governed by the International Steering Committee (ISC) consisting of a Chairman, a network Coordinator from the host institution and nine elected members from across the globe representing the international organisations FAO, IUFRO, ITTO, DANIDA, the Forestry Commission of Ghana and other international bodies besides representatives of non-governmental organisations. No country is represented by more than one member.

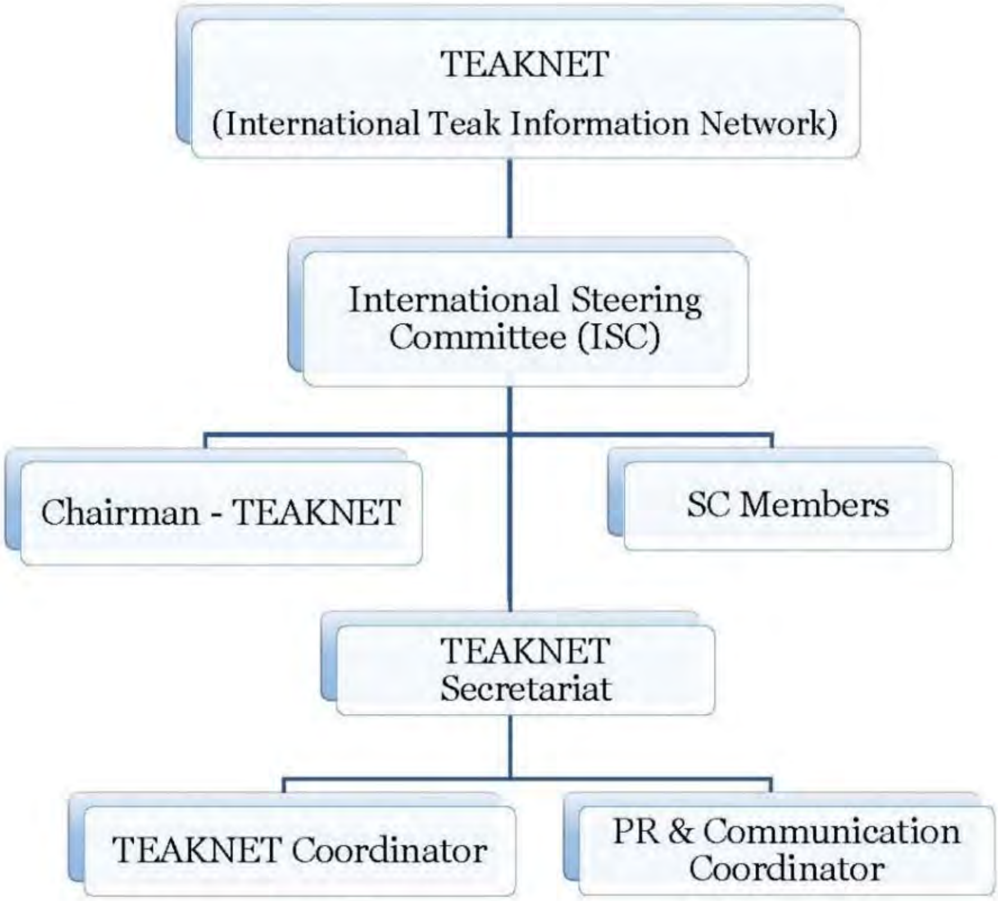


Figure 26-1 Organigram of TEAKNET

The Kerala Forest Research Institute (KFRI) serves as the host institution, providing office space, internet access, and logistical support for running the secretariat of TEAKNET. The Chairman will preside over the meetings and the Coordinator is ex-officio member of TEAKNET and Member-Secretary of the Steering Committee. The term for the members of the Steering Committee is for a period of five years which is extendable. The Coordinator in coordination with the members of the Steering Committee will formulate the annual work plan that has to be approved by the ISC. The ISC is also responsible for the monitoring and control of TEAKNET´s operations, including its finances. The annual work plans include projects for the provision of financial and material support, especially with regard to funding research projects and participation in meetings. TEAKNET addresses the interests of all the categories of stakeholders related to teak, starting from growers, traders, researchers or other groups with a profound interest or concerned with teak. Currently, there are over 49 countries represented in TEAKNET of which 12 are located in Asia, 13 in Latin America, 11 in Africa, 1 in America and 12 in Europe. In total, 159 individual members and 35 institutional members constitutes the backbone of TEAKNET. The different membership options available are shown in the Table 26-1.

Table 26-1 Details of membership options

Membership Fee	Annual (USD)	Lifetime (USD)
Individual	30	400
Institutional/Organization	250	4000

Networking and Dissemination of Data and Information

In 2017, the Secretariat of TEAKNET was relocated to the Kerala Forest Research Institute (KFRI) with the financial support of the FAO Regional Office for Asia-Pacific, Bangkok. Even though established as a network for Asia-Pacific, the ever increasing area of planted teak forest world-wide, it has evolved swiftly into an international teak information network to serve the global teak community. Some of the fundamental activity of the TEAKNET Secretariat is summarised below.

Website and Newsletters

A dedicated website of TEAKNET (www.teaknet.org) was launched and a quarterly online newsletter *"TEAKNET Bulletin*" was released as a first step for information dissemination and another bimonthly online newsletter "*Teak Mekong Newsletter*" related to the ITTO Teak Mekong project since 2019.

The website contains directories of growers, traders and researchers, information on events related to teak at an international level, information on teak related publications and developments in technology, and news and alerts service. The Secretariat maintains a global teak information centre wherein available literature of more than 6000 records related to scientific papers, research reports, information bulletins on teak cultivation and nursery practices, books and proceedings etc. on teak are stored. General information stored on the Website is available to the general public, while specific professional data and information are only accessible for members.

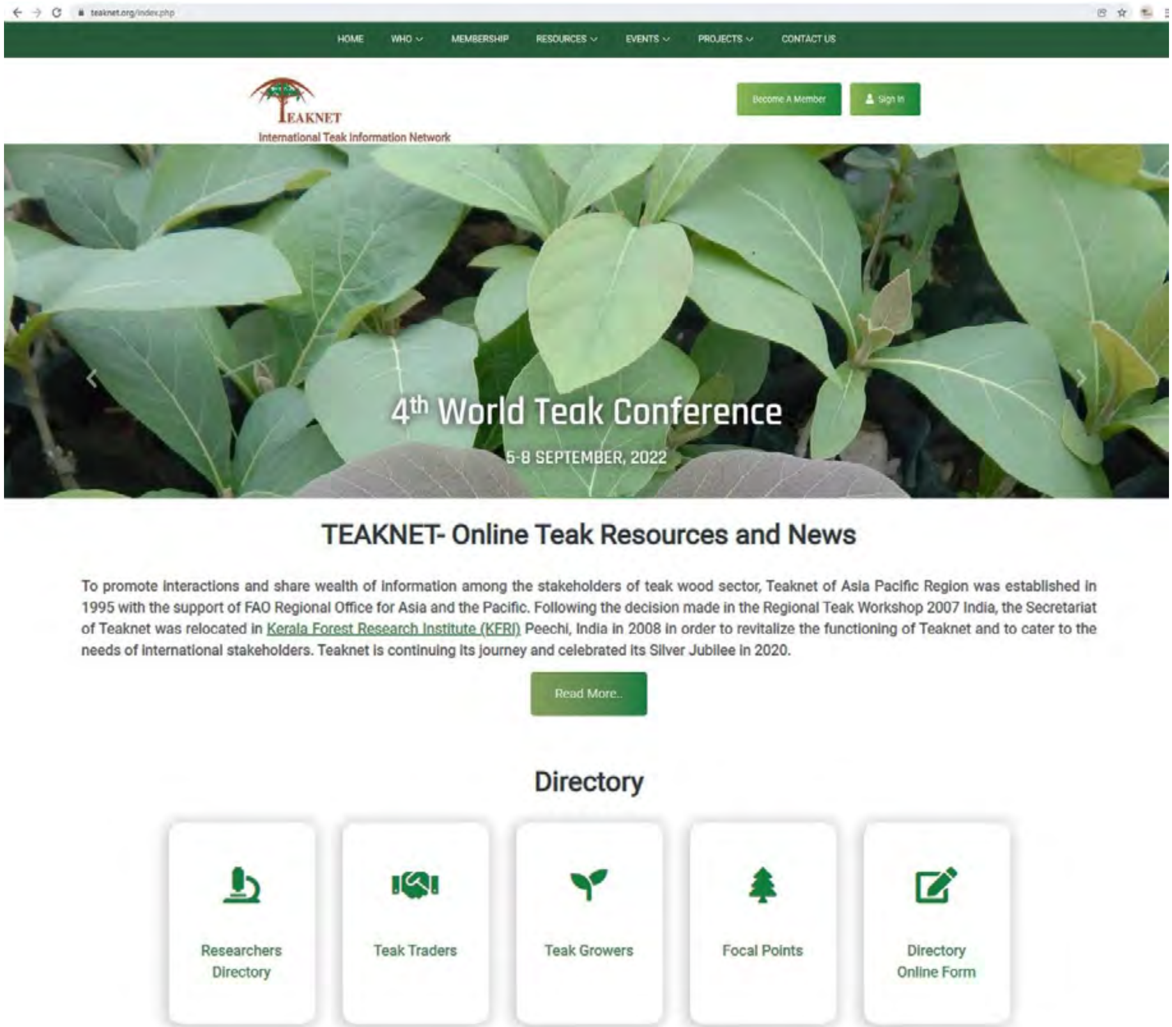


Figure 26-2 The Home Page of the TEAKNET Website (www.teaknet.org)

Capacity Building and Consultancies

Over 25 years of its establishment, the network supports the interests of the teak researchers, growers, loggers, traders, farmers, scientists, and policymakers alike. Considering the diversity and complexity of problems facing the global teak sector, TEAKNET maintains a directory of specialist professionals of teak researchers in our network at regional and international levels and has developed an expert-databank, a flexible arrangement depending on the interest of network members for sharing their expertise to solve specific problems confronting teak cultivation and management, pest and diseases etc. in their countries/regions. For example, TEAKNET upon request of the Research Institute of Tropical Forestry (RITF), Guangdong, P.R. China had organized a one-week training programme and study visit to natural teak forests and teak plantations for the visiting scientists of the institute (Photo 26-1).

Figure 26-3 Examples of publication media issued by TEAKNET

Furthermore, TEAKNET provides scientific support in accordance with the specific needs of the international teak community. TEAKNET nominated a Scientist to RITF to provide professional advice and recommendations on the silvicultural management of their teak plantation in Guangdong and Hainan province. A teak silviculturist was nominated as a consultant to Tanzania for the professional establishment and maintenance of teak plantations for a private plantation enterprise in another international joint initiative. TEAKNET has undertaken many teak cultivation and management training programmes for the benefit of smallholder farmers and plantation professionals (see Table 26-2).

Photo 26-1 Visiting scientists of RITF to Teak plantations in Kerala

Table 26-2 Consulting Services Organized and Implemented by TEAKNET

Month/year	Recipient organisation	Country	Topic
September 2011	Future Forests	Fiji	Management of teak plantations, genetic improvement and raising equity in in PNG, Solomon Islands, and the Fiji
March 2013	Laity and Associates	Australia	Small Holder Teak Plantations in South Pacific Region
February - March 2014	Research Institute of Tropical Forestry, Chinese Academy of Forestry	P.R.China	Interactive Meeting with the Chinese Teak Researchers on global teak cultivation and trade, short rotation teakwood quality and its products and silvicultural management of *Tectona grandis*
December 2014	The Dollar Business Magazine	India	Overview of the global teakwood industry and teak trade
March 2017	Carbon Planet Ltd.	Tanzania	Establishment and maintenance of teak plantations in Tanzania

World Teak Conferences

TEAKNET in collaboration with FAO, IUFRO and ITTO co-organized three World Teak Conferences in Costa Rica (2011), Thailand (2013) and Ecuador (2015) that were attended by over 1,000 representatives of the major teak growing countries in Asia/Oceania, Africa and Latin America. One output of these 3 conferences is an international initiative directed by IUFRO, ITTO, FAO and TEAKNET to promote the initiation of an international research, development and cooperation program to strengthen the conservation and sustainable use of teak resources for the benefit of teak growers, forest industries, investors and local communities. This cooperation resulted in the publication of the "Global Teak Study" as *IUFRO World Series No 36* (available at https://www.iufro.org/publications/series/world-series/) and the ITTO-supported project "*Enhancing Conservation and Sustainable Management of Teak Forests and the Legality of Wood Supply in the Greater Mekong Sub-region*"that includes the five countries Cambodia, Lao PDR, Myanmar, Thailand and Vietnam and is still on-going until September 2022.

The 4th World Teak Conference is planned during 5-8 September 2022 in Ghana with the theme "*Global teak market: Challenges and opportunities for emerging markets and developing economies*". The conference will focus on genetics, silviculture, socio-economics and environmental issues that have an impact on the production, marketing and trade of teakwood. The WTC's held once every 4 years will be a great opportunity to exchange knowledge and experiences on technological innovations and stay up to date on the emerging trends in teak management and trade. It will provide a major meeting place for worldwide researchers, students, entrepreneurs and professionals in the forestry sector to come together, share their knowledge and networks and enter into new business relationships.

Records of the Teak Trade in the International Customs Tariff

One issue facing the teak timber trade is the lack of authentic trade data on an international level. Up to the beginning of the year 2022, the international teak trade was difficult to assess as teak roundwood was recorded under the six-digit HS code 4403.49 as "other tropical roundwood" and 4407.29 "other tropical sawnwood" as reported by many traders in WTC meetings. The Harmonized Commodity Description and Coding System (in brief, the Harmonized System, or HS) is an internationally standardized system of codes and names for classifying traded products. It has been developed by the World Customs Organization (WCO), an independent intergovernmental organization based in Brussels, Belgium. The HS is applied by more than 200 countries as a customs tariff and a means for collecting international trade data. The Global Trade Atlas, operated by Global Trade Information Services (GTIS), provides such data according to HS codes for all member countries of the WCO. New codes for teak and other wood products in HS 2022 were created upon request submitted to World Customs Organisation (WCO) by the Food and Agriculture Organization of the United Nations (FAO), Rome. As of 1st January 2022, the international trade of teak roundwood and sawnwood will be recorded in the Harmonized System nomenclature 2022 Edition (HS 2022) under the new customs codes HS 4403.42 and 4407.23, respectively. After 1st January 2022, the assessment of the significance of the international teak trade will be considerably improved and will give policy- and decision-makers, investors and managers a better understanding of the important role that teak resources play in the provision of wood products for the national economies of many countries.

International Cooperation Projects

In 2014, IUFRO Special Programme for Developing Capacities (IUFRO-SPDC), FAO and TEAKNET with Plant Genetic

Conservation Foundation (RSPG), Thailand as local host, jointly organised a project formulation workshop in Bangkok and invited selected country partners from the Asia Pacific with the specific objective at developing capacity building for the sustainable management and genetic conservation of teak resources in the participating Asian nations that faces severe depletion of teak genetic base (Photo 26-2).

Photo 26-2 Participants at the Bangkok Workshop

In the same way, another pre-project workshop was organised during the 3rd World Teak Conference 2015 at Guayaquil, Ecuador for developing a comprehensive project proposal for planted teak forests.

Planning and Implementation of Side Events

Many Partner Events were conducted by TEAKNET in collaboration with IUFRO, FAO and ITTO at Philippines during Asia-Pacific Forestry Week (2016), IUFRO All Division 5 Conference in Vancouver (2017), and at FAO's Planted Forest Conference in Beijing (2018) and lastly at Curitiba, Brazil in the IUFRO World Congress (2019).In all these meetings the key messages of enhanced dialogue, information and knowledge exchange on sustainable teak forest management, production and sustainable supply chain, as well as sharing experiences with wider audiences globally through participation is disseminated. TEAKNET is organizing a Side Event in the upcoming FAO's World Forestry Congress during May 2022 in Seoul, S. Korea with the theme "New opportunities for Teak sector in the post COVID-19 Scenario" in association with IUFRO Teakwood Working Party (Div5.06.02) and ITTO, Japan.

Global Teak Study Report

In December 2016, with funding support from ITTO and FAO, a team of 12 IUFRO scientists and other teak experts from 11 countries analyzed and compiled globally available state-of-the-art scientific and empirical knowledge on teak, and in 2017 published the results in "*The Global Teak Study - Analysis, Evaluation and Future Potential of Teak Resources*[13]" as IUFRO World Series Volume 36 (see pictures

[13]Kollert, W. & Kleine, M. (2017). *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources*. IUFRO World Series Volume 36, Vienna. https://www.iufro.org/publications/series/world-series/

below). In addition to addressing key issues related to genetic resources conservation, sustainable management, economics, production, markets and trade, the report provides policy recommendations and guidance for future work in promoting sustainable management of natural and planted teak forests in the tropics.

Teak Experts at Vienna

Global Teak Study Report

At the meeting of the FAO's Regional Forestry Commission Asia-Pacific held in Colombo in Oct 2017, IUFRO and TEAKNET disseminated the results of the Global Teak Study and organized a partner event on the significance of teak conservation and its sustainable management in productive landscapes (Photo 26-3).

Photo 26-3 Panellists answering queries from audience

ITTO Teak Mekong Project

ITTO has been supporting teak related projects with a focus on augmenting genetic resource base, seed production as well as sustainable management of teak in Asia, Africa and Latin America since 1990s. Discussions between ITTO and IUFRO on further collaboration on the basis of the recommendations of the Global Teak Study continued during the 53rd International Timber Council Meeting in Lima, Peru in November 2017 and the Global Landscapes Forum in Bonn, Germany, in December 2017. At 53rd ITTC, the Council approved ITTO's 2018-19 Biennial Work Program (BWP) which included an activity entitled "*Enhancing Teak Management*" which is proposed as a comprehensive global activity to improve the management and marketing of both natural and planted teak in all three tropical regions. The ITTO Teak project in Mekong, "*Enhancing Conservation and Sustainable Manage-ment of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region" (PP-A/54-331)* was officially launched in Bangkok in March 2019 for 3 years (36 months) financed by the Federal Republic of Germany through the Federal Ministry of Food and Agriculture (BMEL). The participating countries in the GMS include Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam. The project activity is aimed at assisting governments, local communities and smallholders to enhance natural teak forest management, production and marketing to facilitate the establishment of legal and sustainable wood supply chains while improving national economy and local communities' livelihood enhancement in the Greater Mekong Sub-region.

TEAKNET's Role in ITTO Teak Mekong Project

TEAKNET as a project partner in this ambitious project, handles the project component of information management and networking with the overall responsibility to produce and disseminate outreach materials on teak-based research and development information and the implementation of project activities including sustainable supply chains to research institutions, NGOs, development partners and societies, support and facilitate teak networking in the Mekong Sub-region. In addition, the project findings of the research activities will be disseminated by co-organising the 4th World Teak Conference 2022 in Ghana. Since June 2019 as part of the networking activities, a bimonthly online '*Teak Mekong Newsletter*' was released through the updated TEAKNET website (www.teaknet.org) co-hosted by Kasetsart University, Thailand (see Figure 26-3 under 5.1).TEAK Mekong Newsletter support and facilitates teak networking in the Mekong sub-region through ITTO member countries and partners, and support sharing lessons of the project results through short news release, occasional papers, project related teak-based research and development information.

At the end of the project, it is anticipated to accomplish regional and international collaboration, information sharing and knowledge management, networking have been strengthened far beyond GMS region and capable to move forward with more responsibilities on policy development and outreach on the sustainable management of teak forests, including sustainable use of teak genetic resources to other parts of teak growing countries in Latin America and Africa for the planted teak.

Future Perspectives of TEAKNET

The global scenario with respect to teak has been undergoing changes over the past several years. Over a period of time, there has been a shift in the ownership of forests to the private sector, smallholders becoming major producers of teakwood as in Lao PDR and Indonesia. Supportive policies, legal frameworks and research are needed to expand teak cultivation to non-traditional areas of productive landscapes. The global trade of industrial teak roundwood was found to be slightly more than 1 million m^3, which corresponds to about 7 percent of the total trade volume

(FAOSTAT and Global Trade Atlas; Nautiyal & Kant, 2022). Hence, we should expect a continued spurt in demand and consequent price increases. Competition from alternative products may also increase but their use is generally being discouraged on account of environmental concerns. Demand for legally certified timber and the need for certification of teak plantations are emerging as strong cases. Impact of climate change and trend towards production forestry to conservation forestry are more and more apparent. The future perspectives of the network are built on the gaps in this current scenario. Networking and information exchange have a role to play in bringing together the stakeholders and resolving some of the pertinent issues. Besides continuing with the information exchange, TEAKNET plans to hold more conferences and training programmes on themes of topical importance related to teak. The major tasks ahead for the network are instrumental in enhancing the plantation productivity, producing quality teakwood products, better marketing and affordable prices for the products, market intelligence and bringing unification of log-grading rules. An international database on teak resources and productivity has been long thought of this network. The database will be at the global level with entries for each country on aspects like geographic details of teak growing regions, maps, area under teak plantations both natural forest and home-gardens, productivity of teakwood, export/ import of teakwood, climatic data, soil properties, information on yield table, grading of teak timber, teak prices of different grades, information on traders /buyers/ sellers, wood industries units etc.

Acknowledgments

The authors gratefully acknowledge Dr. Walter Kollert, WaKa – Forest Investments Services AG., Portugal and the Steering Committee member of TEAKNET for the critical review and suggestions on a previous draft of this manuscript.

References

FAO (2014). *The State of the World's Forest Genetic Resources*. Food and Agriculture Organization of the United Nations, Rome, Italy.

Nautiyal, R. & Kant, P. (2022). The rise of India's timber market. *Tropical Forest Update,* 33(3-4), 20-22.

Kollert, W. & Cherubini, L. (2012). *Teak resources and market assessment*. Planted Forests and Trees Working Paper FP/47/E. Edited by Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/forestry/plantedforests/67508@170537/en/

Kollert, W. & Kleine, M. (2017). *The Global Teak Study. Analysis, Evaluation and Future Potential of Teak Resources*. IUFRO World Series Volume 36, Vienna. https://www.iufro.org/publications/series/world-series/

Chapter 27: Teak in Mekong for a Sustainable Future: The Way Forward

P.K. Thulasidas, Hwan-ok Ma, Tetra Yanuariadi, Yongyut Trisurat, and Promode Kant

Summary

The exceptional quality of teak timber, its high value in the global timber market and the case in rising teak plantations, have made it one of the most important species for planting under varied tropical climates across 70 tropical countries. The ITTO Teak Mekong project "*Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region (PP-A/54-331)*" was implemented by ITTO, in five countries in the Mekong region; namely Cambodia, Lao PDR, Myanmar, Thailand and Vietnam with financial support from the Federal Ministry of Food and Agriculture (BMEL), Government of Germany. The aim of the project was to strengthen the conservation and sustainable use of teak genetic resources, enhance natural and planted teak forest management, production and marketing to facilitate the establishment of legal and sustainable wood supply chains while improving national economies of the respective countries and livelihood enhancement of smallholder growers in the Greater Mekong sub-region. The 3- year project (2019-2022) was officially launched in April 2019 in a meeting at Bangkok, Thailand. Despite the Covid-19 pandemic that hindered some of the field oriented activities in certain areas, the overwhelming progress achieved as anticipated in the project supports the participating countries' policies and strategies on sustainable forest management and sustainable wood supply from legal sources in line with their Nationally Determined Contributions (NDCs). The project also contributes to the achievements of SDGs, especially SDG 1 (No Poverty), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on land), and the Global Forest Goals of the United Nations Strategic Plan for Forests 2030 (UNSPF).

The following summary and policy recommendations have evolved from the achievements made under the 3 major outputs envisaged in the project: *Output1*-Conservation of teak genetic resources, sustainable management and use of natural teak forests and market accesses of teak from legal sources have been improved; *Output 2*-Community-based and smallholders teak forest management and agroforestry systems have been strengthened with improved legal and sustainable supply chains; and *Output 3*-Regional and international collaboration, information sharing and knowledge management, networking, policy development and outreach on the sustainable management of teak forests, including sustainable use of teak genetic resources have been strengthened.

1. Management of Natural Teak Forests

Natural teak forests are spread over 29 million ha across India, Myanmar, Thailand and Lao PDR, almost half of which lies in Myanmar alone. In Thailand natural teak forests extend over about 1.3 million ha mainly distributed in northern province while in Lao PDR only about a thousand hectare of natural forests survive along its borders with Thailand. Vietnam and Cambodia do not have natural teak forests. The extent of these natural teak forests has decreased continuously over the past two decades mainly due to over-exploitation, deforestation, and conversion to other land-uses causing severe loss of its genetic resource base. Outside the Mekong region natural forests of teak thrive well in the central and southern peninsular region of India spread over an area of 1.667 million ha.

Several measures have been initiated in these countries to protect these forests but illegal felling still occurs in many places. The current natural distribution of teak in Thailand and Lao PDR as assessed in the 2022 in the GMS region has been secured by ban on harvesting in natural forests but the possibilities of shift over to unsustainable management at some date in future as well as climate change remain medium and long term threats to the natural geographical distribution of teak all over the region. Integration of these forests in regional, national or subnational REDD+ scheme would be helpful in ensuring their long term survival.

2. Teak Plantations

Planted teak forests according to various estimates has reached approximately 6.89 million ha of which 80% are grown in Asia followed by 10% in Africa and 6% in the Latin America. The area under teak plantations has increased in all the GMS countries and the current status of teak plantations in Myanmar, Thailand, Lao PDR, Cambodia and Vietnam is about 411,7; 277,300; 29,000; 6,500; and 3,300 ha, respectively. After India and Indonesia, Myanmar has the largest area of planted teak and the government plantations alone constitute about 395,000 ha while private teak plantations cover 16,200 ha.

- Planted teak forests need to be managed following well-defined operational regime to achieve desired production goals.
- Most important are site selection, use of genetically improved planting stock, soil management, irrigation and fertilization in the first few years, and the timely execution of silvicultural practices.
- Protection against pest and diseases and fire prevention measures are needed to avoid productivity loss. Monitoring of social, environmental, economical sustainability including the enrichment of environmental services of watershed protection, soil conservation, biodiversity conservation and carbon sequestration must be a key component in the management of planted teak forests. Implementation of appropriate practices at every stage of development can help achieve these goals.

3. Conservation of Teak Genetic Resources and Considerations for Tree Improvement

Considering the imminent threat to the fast declining natural teak resources in its native countries and the high risk of losing the diversity of genetic traits of important wood characteristics, the project partner countries in the Mekong basin investigated the genetic variations in the planted and natural populations for breeding and mass propagation. Breeding programmes continue to be developed in many countries like Thailand aiming to improve the timber quality. However, most of these teak stands were established with unknown seed origin. Timber quality has now been improved with selected clones of known genetic origin being produced with high yield and disease resistance from the genetically superior parent plus trees. Clones can be used for establishing monospecific plantations, but intercropping with other species in agroforestry systems and border planting with oil palm in silvopastoral systems provide interim economic benefits as has been successfully practiced in Malaysia and Indonesia.

Myanmar

Tree improvement programme of teak started in Myanmar during 1981 with the establishment of clonal seed orchards consisting of 33 clones. A total of 1,011 plus trees of teak were selected throughout Myanmar representing almost all teak growing regions. Clones from some plus trees were planted in six clonal seed orchards area and seven hedge gardens area, serving as gene pool for *ex situ* conservation. Before 2019, no progeny test or genetic studies of teak clonal seed orchard (CSO) or plus trees had been conducted and the ITTO Teak Project has now provided funding support for a progeny trial to test genetic characteristics of candidate plus trees using clones in gene bank plantation. The results of progeny test will be used to determine plus trees for future tree improvement program of teak in Myanmar. Tissue culture facilities for large-scale production of planting materials from plus trees for commercial plantations are planned to be established. A gene bank of Myanmar teak and a new hedge garden have been set up at Forest Research Institute. Planting materials produced from these labs will be planted in clone bank for mass multiplication and establishment of teak clonal plantations.

Thailand

Teak genetic improvement in Thailand began in 1965 under a bilateral agreement between Thailand and Denmark. Under this program, a total of 636 Plus teak trees were selected based on phenotypical and qualitative traits and tree form. Three sets of clonal test of almost 500 clones have already been conducted at various sites during this Mekong project period and both half-sib and full-sib progeny tests are being conducted. Teak breeding is a long-term process and the results from these ongoing trials should be used to establish protocols for genetic thinning in the seed orchards to further improve the quality of seed sources.

Lao PDR

In Laos, teak genetic improvement dates back to the 1990s as part of the Laos Tree Seed Project. Of the total 102 seed sources, nine are for the teak seed sources established in it natural habitats. The ITTO Teak project in Mekong supports the National Agriculture and Forest Research Institute (NAFRI) in establishing two demonstration plots for teak seed production. A total of 100 mother trees at Thong Khang and 178 at Huay Khodin Xayabuly Province have been selected for teak seed source production for smallholder plantations. In addition, teak seed source from 170 mother trees in Luang Prabang Province have been selected and established. Improved seedlings derived from the selected trees, clone bank and clonal seed orchards have been distributed to farmers for developing plantations.

Cambodia

Natural teak forests do not occur in Cambodia, hence there are no natural teak seed sources in the country. With the support of Teak project in Mekong, Cambodia has established two seed sources at Han Chey Mountain in Kampong Cham Province and Teak silvicultural farm in Kampong Spue Province for production of high-quality seedlings. Teak plantations have raised over about 7,000 ha. Private investment in commercial teak plantations by well known companies offers greater opportunities for harvesting of teak at young agewith high productivity and yield.

Vietnam

Teak is not a native species in Vietnam. Teakwood around 40,000 cu.m are annually being imported to the country and re-process in the sawmills for domestic use and partially exported. The latest forest inventory data showed that teak plantations cover about 6,600 ha, which is just about 0.15% of the country's plantations. The ITTO project in Mekong supports the establishment and maintenance of three teak seed source production centres at Dong Nai Teak Plantation, Son La Teak Plantation and Thanh Hoa Station. Good quality teak seedlings have been prepared at demonstration plots and more than 6,000 high quality seedlings have been distributed to smallholders. The target number is 15,000 seedlings.

In general, the sustainable development of teak sector requires:

- enhancing the *in situ* and *ex situ* conservation of teak genetic resources through the establishment of seed production areas and seed orchards. There is also a need for long-term teak improvement research and development programs to supply high quality seeds for teak plantations and joint research on the conservation of teak genetic resources linked with breeding and biotechnology tools. This includes transfer of seeds for plantations and improved genetic materials subject to national regulations in the Mekong sub-region to improve the genetic base of populations and avoid genetic erosion. Transfer of genetically improved planting material across regions/countries may be facilitated with the involvement of network organisations (like TEAKNET and APFORGEN)

- Advanced technology such as DNA markers is now available to accelerate the genetic improvement of teak.
- Teak clonal forestry has demonstrated its efficacy for establishing fast growing plantations with enhanced yield. Superior teak clones have been widely deployed with known genetic origin for higher productivity in many countries like Malaysia, Indonesia, Brazil, Costa Rica, Tanzania, India etc at shorter rotations of 20-25 years or even less.
- Smallholder farmers should be able to access the improved genetic material of teak so that the productivity of their plantations and the quality of the timber can be improved, which eventually will increase their income. Improving silvicultural aspects of teak plantations, from the selection of suitable sites to thinning and harvesting techniques, is urgently required. There is a strong need to share knowledge and experiences in the sustainable management of teak plantations.

4. Community-based Smallholders Teak Forest Management

Smallholding teak production has become an important source of raw material for furniture industry in many countries of South East Asia. The opportunities and challenges of smallholders teak in Mekong Basin are multifaceted. The potential of smallholder teak farming systems is hindered by limited access to quality planting material, poor silvicultural management, difficult market access and policy disincentives. In the last 3 years, 14 demonstration plots have been established for production of good quality seedlings that was freely distributed to interested local communities and smallholders. In addition, learning centres for good agro-forestry and silvicultural systems and practices has been included for small-scale plantations. Training programmes has been conducted for the capacity building of government staff in central and field offices, teak farmers and interested individuals on the following themes: (1) Seed production/nursery techniques, (2) Silvicultural practices and improved stand management, (3) Minimizing harvesting loss, efficient transport and processing of teak roundwood, and (4) Supply chains control and marketing. The opportunities and challenges of smallholders teak in Mekong Basin are multifaceted.

- The value chain analysis (VCA) revealed key challenges/impediments faced by smallholder teak plantations. The private smallholder woodlots are poorly managed, unproductive, poor seed sources and lack of awareness about the thinning regimes for profitable earnings. The site quality of teak woodlots was lower when compared to many other countries. They are fragmented and far from market centres, unable to accommodate the high transportation costs involved in the international certification systems, and relying on middlemen/traders to sell and harvest the logs. Secured land tenure and user-rights are essential for smallholder teak plantations to run the industry profitably. Supportive tenure policies for smallholders teak plantations can be effective in eliminating excessive regulatory burden on small-scale plantations in management and harvesting as well as local transportation of harvested wood products. Increase in the productivity and quality of smallholder teak plantations can be brought about by using best quality genetically improved planting materials. It is important to identify and promote good siliviculture practices of pruning and thinning, socio-economic and policy conditions that support smallholder's quality production of teakwood. The provision of regular training and extension are essential for this purpose

- Value addition to small sized thinned teak is essential to ensure significant interim earnings for the smallholder before the final harvest. Much progress has been made in this in Java which can be extended to the Mekong region through special efforts by the agencies responsible for it in the countries of the region. Upgrading the processing machinery may also improve product standards and thereby access to better paying markets. Financial incentives in the form of soft loans and setting up of specialized banks for this purpose will also be helpful in promoting smallholder teak planting. Overall the national governments should encourage and support smallholders and communities to plant teak through incentive programs, enhance their access to finance and long-term investments, improve networking, and strengthen market support and formation of cooperatives of farmer groups for effective value chain development.

5. Trade, Certification and Legality

One increasingly important consideration influencing trade of teakwood products both from plantation-grown and natural teak forests is forest management certification and legality issues. Timber markets in Europe and North America fetching premium prices for teak products now require legality and sustainability for establishing the legal origin, production and trade of timber. Legality and sustainability are a complex issue for many teak growing tropical countries and should be improved from the development and implementation of a competent monitoring system supported by a set of criteria, indicators, and verifiers to demonstrate the legality and sustainability. The digitalization of forest management activities and cost-effective verification tools are increasing important in tropical countries. Large-scale teakwood producers in some countries like Brazil, FSC certified teakwood from sustainable sources are being traded across the globe at high prices and many short-rotation plantations now opt for global certification schemes such as PEFC and FSC or adopt their own country level certifications. However, high transaction costs of complying with the environmental and social standards required in certification process deter the smallholders in Mekong region from adopting it.

For sustainable teak plantation management, legal source and supply chain control need to be strictly enforced. Establishing transparent and traceable timber supply chains will provide teak growers in Mekong region more opportunities to participate in global markets while addressing global environmental issues. However, there is an increasing need to develop and implement innovative certification systems that substantially reduce transaction costs for smallholder teak planters who are unable to bear the high transaction costs involved in the existing certification system. The certification of smallholder teak plantations by local forestry authorities, as is being done under the Luang Prabang Teak Program in Lao PDR, is one such example.

6. Regional Network and International Collaboration

International collaboration and regional networks on forest genetic resources of natural and planted teak should be strengthened. Organizations like TEAKNET in partnership with IUFRO and ITTO should periodically organize teak conferences that may suggest action plans and policy recommendations for sustainable teakwood trade and supply chains. Extension services for teak growers should be made more effective through the publication of teak grower's manuals in local languages designed especially for different target groups. Development of appropriate quality standards and accreditation schemes for teak planting material including germplasm production and exchange should be encouraged and promoted. TEAKNET has made significant contribution in sharing research outcomes and policy briefs among the participating countries through online Mekong newsletter circulated globally through the websites of both Kasetsart University and TEAKNET and these efforts should continue in future. There is a need to carry the regional and international collaboration, information sharing and knowledge management already accomplished in the region to other parts of teak growing countries in Latin America and Africa.

.

INDEX

A
absolute form factor, 165, 168, 175, 177, 178, 180
Africa, 5, 18, 51, 62, 101, 149, 155, 212, 242, 250, 270, 326, 339, 346
agroforestry, 4, 10, 15, 54, 63, 66, 80, 91, 215, 277, 315, 322, 352
appropriate technology, 210
B
bee-hole borer, 144, 145, 149, 150, 151
biotechnology, 156, 252, 270, 355, 155
Brandis, 26, 315, 317
Brazil, 19, 105, 149, 161, 182, 186, 235, 275, 277, 324, 347, 357
breeding, 8, 28, 34, 49, 70, 130, 135, 156, 161, 251, 257, 265, 270, 353
breeding plan, 135, 137
British, 23, 316, 319
Buton, 156, 157, 161, 216, 217
C
Cabinet, 3, 33, 318
Cambodia, 3, 10, 62, 63, 88, 91, 102, 276, 288, 318, 322, 354
clonal test, 2, 8, 19, 118, 125, 130, 186, 245, 253, 260, 268, 279, 354
clones, 7, 118, 122, 130, 135, 157, 186, 219, 248, 253, 258, 271, 274, 353
colonial period, 300
COVID-19, 3, 13, 235, 237, 297, 347, 352
D
disease(s), 8, 16, 28, 33, 81, 144, 149, 185, 193, 257, 315, 335, 343, 353
DNA markers, 160, 276, 355, 357
E
economic benefit, 22, 72, 220, 336, 353
enrichment planting, 46, 78, 81
export, 10, 18, 23, 30, 38, 51, 57, 62, 156, 185, 196, 233, 239, 270, 288, 311, 320, 334, 354
extraction, 43, 48, 205, 302, 307, 316, 334
F
FAO, 18, 28, 39, 87, 304
financial constraint, 218
FIO (or Forest Industry Organization), 8, 13, 28, 32, 118, 251
forest industry, 339
fruit set, 130, 139, 140
full-sib, 8, 119, 121, 130, 245, 251, 261, 267, 354
furniture, 119, 156, 196, 213, 233, 240, 311, 330, 355
G
genetic conservation, 19, 49, 150, 160, 246, 252, 346
genetic diversity, 7, 88, 159, 160, 280
genetic improvement, 8, 28, 33, 46, 70, 80, 156, 159, 177, 185, 252
germplasm, 8, 28, 33, 46, 70, 80, 156, 159, 177, 185, 252
Greater Mekong Sub-region (or GMS), 2, 41, 62, 87, 101, 297, 349, 352
H
half-sib, 8, 121, 130, 245, 251, 266, 354
hand pollination, 130, 133, 136, 137, 139
harvesting plan, 202, 203, 204
harvesting, 13, 16, 26, 41, 51, 57, 74, 92, 120, 184, 193, 202, 206, 216, 285, 292, 299, 30
I
import, 18, 30, 37, 57, 232, 239, 285, 198, 320, 350
in vitro, 49, 270, 271, 273, 274

income, 15, 23, 42, 51, 62, 156, 218, 220, 277, 324
India, 15, 23, 42, 51, 62, 156, 218, 220, 277, 324
Indonesia, 19, 28, 62, 69, 87, 101, 155, 156, 212, 214, 217, 239, 250, 255
insect pest, 19, 144, 145, 149, 150
intercropping, 10, 56, 63, 65, 215, 220, 276, 353
International Tropical Timber Organization (or ITTO), 3, 10, 34, 63, 69, 87, 105, 202, 230, 232, 249, 256, 285, 292, 297, 331, 339, 347, 349
J
Java teak, 157, 216, 220

K
knowledge management, 18, 19, 339, 349, 352, 358
L
Lampang, 8, 13, 22, 28, 118, 150, 247, 250, 256, 268
Lao PDR, 2, 9, 51, 53, 92, 291, 321, 354
leaf blight, 144, 145
light thinning, 165, 167, 169, 173, 175
live-crown ratio, 165, 168, 175, 179, 180
logging ban, 5, 26, 30, 44, 102, 319
logging concession, 23, 301, 322
Luang Brangbang, 9, 13, 51, 53, 54, 57, 60, 92, 321, 326, 354
M
Malaysia, 19, 32, 150, 186, 223, 235, 239, 270, 329, 353
mean basal area, 165, 168, 169
mean stem volume, 165, 168, 169, 179
mean volume increment, 175
Mistletoe, 144, 145, 147
moderate thinning, 169, 171, 172, 175, 177
Modified Myanmar Selection System, 87, 94
Muna (teak), 101, 155, 156, 157, 159
Myanmar, 2, 4, 5, 7, 28, 37, 41, 44, 205, 212, 235, 288, 290, 296, 308
N
NAFRI, 3, 9, 89, 354
natural teak forests, 9, 23, 25, 41, 52, 62, 87, 92, 102, 105, 246
networking, 4, 16, 18, 19, 339, 342, 349, 358
P
phenology, 130, 131, 135
plus tree, 7, 8, 13, 80, 118, 119, 161, 219, 245, 257, 266, 278, 321, 328, 354
plywood, 28, 71, 235, 239
pollination, 8, 28, 130, 131, 132, 133, 134, 135, 136, 137, 139
productivity, 130, 131, 132, 133, 134, 135, 136, 137, 139
progeny trials, 7, 159, 245, 251, 266, 278, 354
provenance trials, 7, 159, 245, 251, 266, 278, 354
Q
QGIS, 88
R
ramet selection, 135
RFD, 3, 8, 15, 26, 32, 33
rubber, 10, 55, 56, 73, 277
rubber wood, 27, 33, 56
Rust, 144, 145, 147
S
sawn timber, 32, 38, 311, 321, 336
sawnwood, 63, 70, 151, 346
SDG, 3, 232, 352, 358
seed source, 9, 10, 33, 52, 54, 59, 72, 78, 82, 118, 159, 250, 323, 354
silvicultural practice, 10, 13, 19, 68, 70, 218, 354, 355
silviculture, 14, 44, 78, 82, 156, 185, 212
site condition, 82, 84, 132, 253
slenderness ratio, 165, 168, 175, 177, 179
smallholder, 2, 3, 10, 16, 17, 27, 52, 56, 85, 157, 212, 277, 289, 315, 322, 327, 330
smallholder plantation, 9, 56, 212, 331, 353
Son La, 10, 13, 15, 84, 97, 355
South America, 51, 101, 149, 183, 199, 212
stand volume, 81, 165, 168, 169, 173, 175, 180
superior clones, 261, 262
superior teak, 46, 155, 157, 160, 186, 280, 355
supply chains, 2, 11, 13, 15, 18, 19, 33, 72, 194, 233, 237, 285, 292, 297, 299, 305, 306, 307, 355
T
Taungya, 10, 27, 44, 97, 317
teak defoliator, 149, 151, 152
teak pest, 144, 149
teak plantations, 10, 27, 28, 37, 44, 53, 63, 65, 71, 78, 90, 144, 165, 182, 214, 223
teak woodlot, 54, 60, 355
Thailand, 2, 4, 8, 22, 25, 94, 118, 130, 149, 165, 245, 256, 318, 319
Thanh Hoa, 10, 13, 82, 84, 97
Thinning, 43, 69, 165, 168, 173, 175, 227, 332

timber harvesting, 26, 202, 204, 285, 322
timber legality, 44, 161, 285, 289, 290, 292, 298,300
timber market, 2, 161, 285, 289, 298, 352, 357
timber products, 56, 75, 232, 233,294, 296, 299, 356
timber trade, 15, 32, 232, 289, 292, 293, 294, 346
Tree felling, 33, 205, 322, 333
tree improvement, 7, 13, 130, 159, 161, 248, 251, 353, 354
tropical timber, 3, 15, 42, 87, 182, 232, 233, 234, 285, 290
tropical wood products, 232, 234, 237, 242
U
UNFCCC, 330, 331
unthinned, 166, 169, 171, 173, 175, 178, 179
Vietnam, 2, 10, 78, 80, 97, 237, 240, 291, 323, 354
W
wood industry, 22, 33, 78, 85, 345
wood quality, 8, 34, 58, 101, 156, 257
work safety, 207, 209