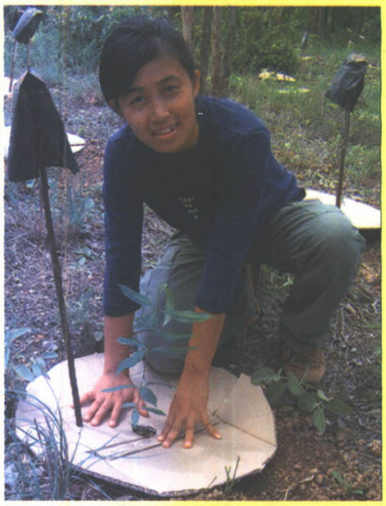

How to Plant a Forest:

The Principles and Practice of Restoring Tropical Forests

By The Forest Restoration Research Unit
Chiang Mai University

FROM THIS...

Upper watershed, Mae Sa Valley, Doi Suthep-Pui National Park, 1998.

...TO THIS..

Same area, 2004

..IN JUST 6 YEARS? TO FIND OUT HOW...READ ON...

HOW TO PLANT A FOREST:

THE PRINCIPLES AND PRACTICE OF RESTORING TROPICAL FORESTS

"We climb the highest mountain.
We'll make the desert bloom.
We're so ingenious; we can walk on the moon.
But when I hear of how the forests have died,
salt water wells in my eyes."
- Julian Lennon

THE FOREST RESTORATION
RESEARCH UNIT (CMU)

COMPILED BY
STEPHEN ELLIOTT, DAVID BLAKESLEY, J. F. MAXWELL,
SUSAN DOUST AND SUTTHATHORN SUWANNARATANA

ARTWORK BY SURAT PLUKAM

SPONSORED BY THE UNITED KINGDOM'S
DARWIN INITIATIVE

FIRST EDITION 2006

"How to Plant a Forest" is also available in Thai. Adaptations in Chinese, Lao and Khmer are being prepared. This book has no copyright and has been designed to be easily reproduced. All we ask is that proper acknowledgement is made as to the origin of the material. **Please cite as:**

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Additional copies (in English or Thai) are available from The Forest Restoration Research Unit, c/o Dr. Stephen Elliott or Dr. Sutthathorn Suwannaratana. For contact details, see page 200.

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Cover Photographs

Top *- Deforested, cultivated, abandoned, burnt and degraded, the watershed above Ban Mae Sa Mai in Doi Suthep-Pui National Park is typical of areas suitable for forest restoration.*
Bottom *- The same area, 7 years after planting 30 framework tree species.*
Centre *- Planting a tree, with cardboard mulch to reduce weed competition.*

DEDICATION

This book is dedicated to the memory of M.R. Smansnid Svasti (1932-2003), better known to her friends simply as "Nunie". A keen naturalist, Nunie was instrumental in helping us to establish FORRU-CMU. Her vision that forests in northern Thailand could be replanted and her enthusiasm for our work continue to inspire us today.

I shall miss her friendship and unwavering encouragement, her stimulating conversations and her insatiable curiosity during walks in the forest. But more importantly, the natural world has lost one of its most ardent defenders and is the more vulnerable for her passing."
– Stephen Elliott (from Nunie's memorial book, 2003)

Nunie relaxes after her presentation entitled "Rivers in Jeopardy" at the workshop "Forest Restoration for Wildllife Conservation", organized by FORRU-CMU in 2000 and sponsored by the International Tropical Timber Organization.

Contents

ACKNOWLEDGEMENTS

This manual cannot be ascribed to a single author or even a small group. The information within it has been contributed by the many people who have participated in the research and education programs of Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) since 1994. The compilers listed on the title page are those who have collated information that has been generated over more than a decade.

This manual is one of the outputs from the project entitled "Education and Training for Restoring Tropical Forest Biodiversity", sponsored by the United Kingdom's Darwin Initiative. We are very grateful to the Darwin Initiative for sponsoring production costs and for arranging review of the first draft.

FORRU-CMU was co-founded by Assoc. Prof. Dr. Vilaiwan Anusarnsunthorn, Dr. Stephen Elliott and Dr. David Blakesley in 1994, within Chiang Mai University's (CMU) Biology Department and in association with the Headquarters staff of Doi Suthep-Pui National Park, where the unit's research nursery was built. We are especially grateful to all the park chiefs who have provided logistical support for the unit over the years, including Mr. Prawat Wohandee, Mr. Amporn Panmongkol, Mr. Wirote Rojanajinda, Mr. Suchai Omapinyan, Mr. Paiboon Sawetmalanon, Mr. Prasert Saentaam, Mr. Anan Sorngai and Mr. Surachai Tuamsomboon.

This book would not have been possible without the dedicated work of FORRU's staff, both past and present, including Ms. Siriporn Kopachon, Ms. Kittiya Suriya, Mr. Puttipong Navakitbumrung, Mr. Cherdsak Kuaraksa, Mr. Greuk Pakkad, Ms. Panitnard Tunjai, Ms. Narumon Tantana, Ms. Thonglaw Seethong, Ms. Jahmbee Bunyadit, Ms. Somkit Kungotha and Mr. Kunya Seethong. FORRU's Darwin Education Team, provided much feed back on earlier drafts of the book, including Ms. Natenapit Jitlam, Mr. Wasun Leerat, Mr. Kunakorn Boonsai, Mr. Thanakorn Lattirasuvan, Ms. Sudarat Zangkum, Ms. Narrisa Pongsopa. Ms. Rungtiwa Bunyayod helped with layout and designed the Thai edition.

Over the last ten years, FORRU benefited greatly from fresh ideas brought in by many volunteers including Mr. Daniel Blackburn, Mr. Alan Smith, Ms. Anne Sinclair, Mr. Simon Gardner, Ms. Pindar Sidisunthorn, Mr. Derek Hitchcock, Mr. Kevin Woods, Ms. Janice Kerby, Mr. Tim Rayden and Ms. Amanda Brigden. In particular, Australian Youth Ambassador, Mr. Kirby Doak provided substantial input into Part 8 of the book and Ms. Susan Doust drafted Part 9. We also thank Dr. Kate Hardwick, for her intellectual input during FORRU's formative years. The late M.R. Smansnid Svasti and the late Mr. Mark Graham are fondly remembered for their assistance with establishing the unit.

The framework species method of forest restoration was first conceived in Queensland Australia and we are indebted to Mr. Nigel Tucker and Ms. Tania Murphy for training FORRU-CMU staff in the concept at Lake Eacham National Park, Queensland, in 1997. Dr. Nancy C. Garwood from the Natural History Museum, London, U.K. also provided training for FORRU's staff during the unit's establishment phase.

Collaboration with the villagers of Ban Mae Sa Mai has been essential for the success of this project, particularly the establishment of the experimental plots there. We thank Mr. Naeng Thanonworakun, Mrs. Nahor Thanonworakun and their family, for taking care of the village tree nursery and for co-ordinating our work with the community.

FORRU-CMU was founded with sponsorship from Riche Monde (Bangkok) Ltd. Its research has subsequently been supported by Chiang Mai University, Thailand's Biodiversity Research and Training Program, The U.K.'s Eden Project, Shell International Renewables and Guinness PLC. Other donors have included the British Embassy in Bangkok, the British Council, The Fagus Anstruther Memorial Trust, The Peter Nathan Trust, The Robert Kiln Charitable Trust, the Barbara Everard Trust for Orchid Conservation, The Rotary Club of Cleveland, Tennessee, The Pondan Project, Mr. Alan and Ms. Thelma Kindred, Mr. Nostha Chartikavanij, Mr.

R. Butterworth and Mr. James C. Boudreau. the sponsors or reviewers. The compilers would

R. Butterworth and Mr. James C. Boudreau. We thank them all.

The text of this book was compiled by Dr. Stephen Elliott, Dr. David Blakesley and Ms. Susan Doust. The Thai edition is being adapted by Dr. Sutthathorn Suwannaratana. J. F. Maxwell identified all plants mentioned in the text and made significant improvements to drafts of Parts 2 and 9. All artwork is by Mr. Surat Plukam, unless otherwise attributed. Photographs were taken by FORRU-CMU staff.

All opinions expressed in this book are those of the compilers and not necessarily those of the sponsors or reviewers. The compilers would like to take this opportunity to thank anyone, not already mentioned above, who has contributed in any way towards FORRU-CMU's work or the production of this book.

Finally we are grateful to the Biology Department, Science Faculty, Chiang Mai University for institutional support of FORRU, since its inception and East Malling Research (formerly Horticulture Research International) for institutional support of Dr. David Blakesley and for acting as collaborative U.K. partner for Darwin Initiative projects.

Dr. David Blakesley of Wildlife Landscapes, FORRU's Co-founder and long-term Research Advisor.

Mr Naeng Thanonworakul, Nurseryman and community motivator at Ban Mae Sa Mai, hugs a 5-year old Spondias axillaris *tree.*

The FORRU Team at CMU, early 2005. From left to right: Ms Panitnard Tunjai (Researcher), Dr. Stephen Elliott (Co-founder), Dr. Vilaiwan Anusarnsunthorn (Co-founder), Mr J. F. Maxwell (Plant Taxonomist), Dr. Sutthathorn Suwannaratana (Education Management), Mrs Rungtiwa Bunyayod (Secretary), Mr Cherdsak Kuaraksa (Senior Researcher), Dr. Greuk Pakkad (Senior Researcher), Ms Sudarat Zangkum, Mr Kunakorn Boonsai and Ms Narissa Pongsopa (all Darwin Education Officers) and Ms Susan Doust (Australian Youth Ambassador).

A Message from U.K. Environment Minister, Elliot Morley M.P.

Destruction of tropical forests is probably the greatest threat to the enormous variety of plant and animal species, with which we share our planet. Although tropical forests cover only 7% of Earth's land surface, they are home to more than half of the world's plant and animal species. In addition, they provide local people with a wealth of forest products; reduce damage caused by floods and droughts and generate revenue as tourist attractions. Yet these forests are fast disappearing.

In response to the global biodiversity crisis, the British government established the Darwin Initiative in 1992 to promote the use of U.K. expertise to work in partnership with countries rich in biodiversity but lacking all the resources needed to conserve it. So far, this initiative has provided grants totalling £35 million to 350 projects to promote biodiversity conservation around the world.

In 2002, the Darwin Initiative awarded a grant to Horticulture Research International[1] and the Forest Restoration Research Unit (FORRU) of Chiang Mai University in northern Thailand for a project entitled "Education and Training for Restoring Tropical Forest Biodiversity". This project established an education unit to teach local people how to restore tropical forest ecosystems, with the specific aim of promoting biodiversity recovery. The education program was based on original research by FORRU-CMU since 1994, which had shown how it is possible to re-establish closed canopy, tropical forest within 3-5 years after planting 30 or so indigenous tree species, carefully selected for their ability to shade out invasive weeds and attract seed-dispersing animals, which accelerate biodiversity recovery.

Through workshops and other educational activities, this project has enabled more people to become involved in restoring Thailand's once magnificent forests and has helped to improve the efficiency of existing reforestation projects. In addition to passing on technical expertise, the project has also developed innovative ways to encourage local communities to become involved in forest restoration.

In 2004, I visited one of these communities, Ban Mae Sa Mai in Doi Suthep-Pui National Park, and witnessed, at first hand, how this project has generated both a tremendous enthusiasm for forest restoration amongst local people and the technical competence needed to implement it.

This manual is one of the outputs from this project. It provides a simple, accessible and practical guide so that others may apply the findings of the FORRU's research and become actively involved in restoring Thailand's forests. I am delighted that the Darwin Initiative has been able to contribute to its publication and distribution. It not only serves as a guide to the restoration of forests in Thailand, but also as an example for other countries to emulate.

Elliot Morley

U.K. Environment Minister, Elliot Morley, M.P. chats with the Headman of Ban Mae Sa Mai, Kuhn Manat Thanonworakul and the U.K. Ambassador to Thailand, H. E. Mr. David Fall during his visit to FORRU-CMU in 2004.

[1]Now renamed East Malling Research (EMR)

FOREWORD

**BY PROF. VISUT BAIMAI,
DIRECTOR OF THAILAND'S
BIODIVERSITY RESEARCH
AND TRAINING PROGRAM (BRT)**

Like many tropical countries, Thailand faces a biodiversity crisis. As forests are cleared for development and agriculture, the Kingdom's immensely rich flora and fauna are decimated. Recognizing this problem, the Biodiversity Research and Training Program was established in 1995 to support research on the conservation and sustainable use of biological resources.

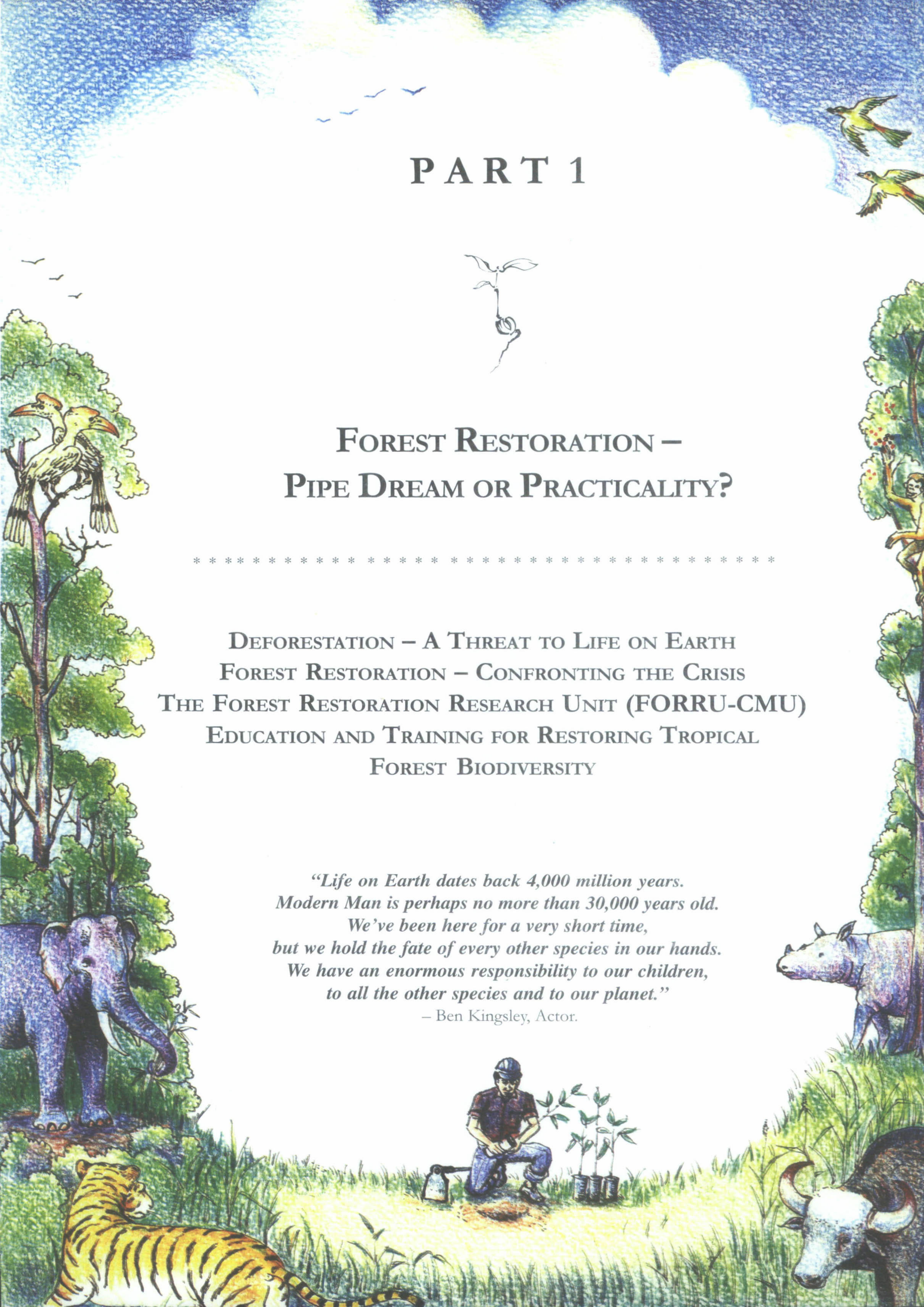
Since 1998, BRT has helped to sponsor the pioneering efforts of Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) in its mission to discover how to re-create biodiversity-rich forest ecosystems where they have been destroyed. This research has resulted in notable success. The unit has developed experimental tree nurseries and an impressive system demonstration plots, where forest has been restored in just a few years, by adapting the so-called "framework species" approach to forest restoration. Many bird and mammal species have rapidly re-colonized these newly planted forests, bringing with them the seeds of more than 60 other (non-planted) tree species.

This book presents the results of that research in a user-friendly format, so that anyone interested in restoring forest ecosystems can do so efficiently and effectively. With its optimistic message that **"deforestation can be reversed"**, this book provides the means to restore biodiversity where it has been depleted, by re-establishing habitat for thousands of plant and animal species.

In addition to clear "how-to-do-it" instructions, the book also provides readers with a basic understanding of forest types and natural forest succession, so that the techniques described can be adapted to various local conditions. There is something in this book for everyone who cares about Thailand's biodiversity and forests, from school children joining their first tree-planting event, to government officials responsible for planning nation-wide reforestation programs.

I am proud of BRT's contribution to the research that generated much of the original information presented in this book and I hope that everyone who reads it will be inspired to get directly involved in restoring our nation's forests and our biological heritage.

BRT
The Thai Response to Biodiversity



PART 1

Forest Restoration – Pipe Dream or Practicality?

* *

Deforestation – A Threat to Life on Earth
Forest Restoration – Confronting the Crisis
The Forest Restoration Research Unit (FORRU-CMU)
Education and Training for Restoring Tropical Forest Biodiversity

***"Life on Earth dates back 4,000 million years.
Modern Man is perhaps no more than 30,000 years old.
We've been here for a very short time,
but we hold the fate of every other species in our hands.
We have an enormous responsibility to our children,
to all the other species and to our planet."***
– Ben Kingsley, Actor.

Education and Training for Restoring Tropical Forest Biodiversity - FORRU/EMR's Darwin Initiative Project

From 2002 to 2005, this project passed on the skills and knowledge required to restore forest ecosystems to community groups and NGOs as well as school children and their teachers. The education/training program was based on original information derived from FORRU's research and enabled local communities to start their own forest restoration initiatives, using proven techniques. This manual is enabling the experiences gained during the project to be passed on to others for many years to come.

More than 180 school events introduced 9,000 children and their teachers to forest restoration concepts and methods (above).

Nineteen workshops showed more than 500 technicians how to include biodiversity recovery in reforestation programs by applying the framework species method (above).

Young students from all over the world were taught nursery techniques (left) before participating in hands-on activities (above).

FORRU NEWSLETTER

September 2003

FORRU Forges Links in southern Thailand To Help Save Thailand's Rarest Bird

by Stephen Elliott

All project participants were kept informed by a newsletter (left); 900 copies (Thai and English) distributed quarterly.

Forest restoration is not just about planting trees. Conservation of seed-dispersing birds is also important for biodiversity recovery. So, a bird conservation club was formed at Ban Mae Sa Mai to persuade children who usually hunt birds to appreciate and conserve them instead (left and above).

FOREST RESTORATION – PIPE DREAM OR PRACTICALITY?

"If we continue at the current rate of deforestation and destruction of major ecosystems like rainforests and coral reefs, where most of the biodiversity is concentrated, we will surely lose more than half of all the species of plants and animals on Earth by the end of the 21st century."
- E. O. Wilson, renowned biologist who popularized the term "biodiversity".

SECTION 1 – DEFORESTATION – A THREAT TO LIFE ON EARTH

Why should I care about forest destruction ?

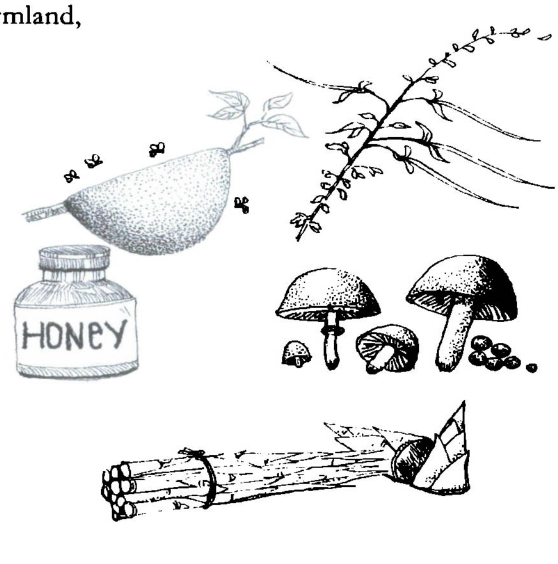
Ever since Humans first forged metal axes, forests have been cleared to make way for agriculture and towns and to provide timber, firewood and a host of other products. In ancient times, tree cutting rarely exceeded the natural capacity of forests to regenerate. Now, however, as the demands of an ever growing Human population have increased, forests and the wealth of species they support, are being devastated well beyond their capacity to recover.

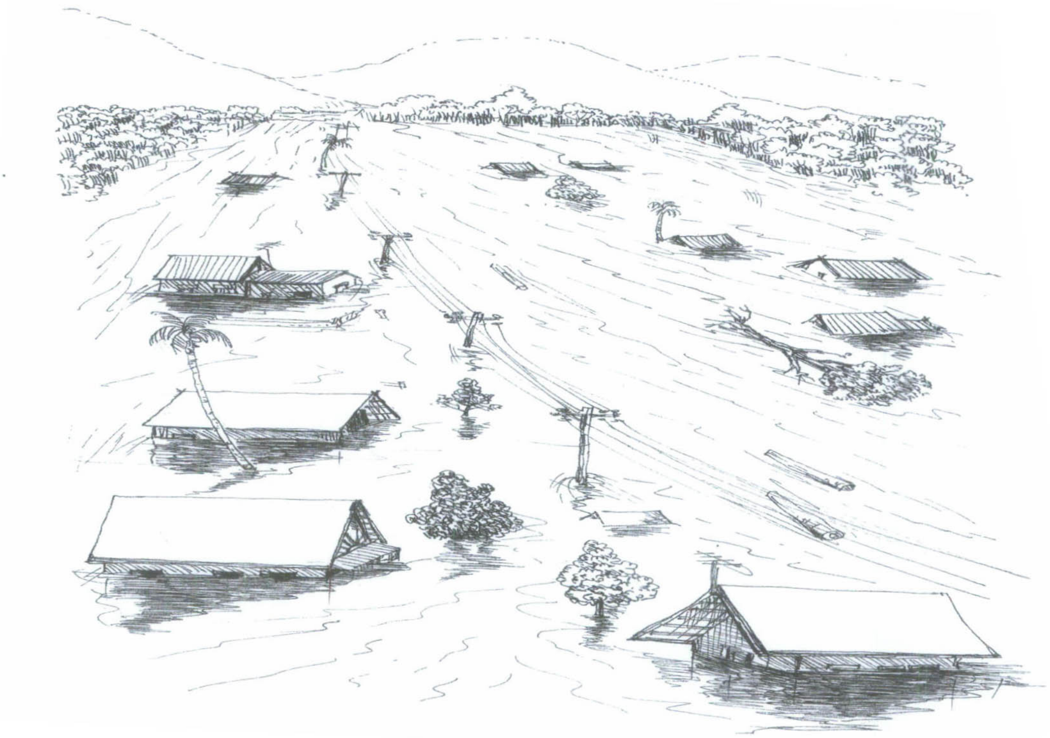
This problem is particularly serious in the tropics. Tropical and sub-tropical forests cover only 16.8 percent of Earth's land area (FAO, 2001), yet they are home to more than half the planet's plant and animal species (Wilson, 1988). Deforestation gradually reduces large forest tracts into tiny, isolated fragments, each of which is incapable of supporting viable populations of plant and animal species, especially large mammals and birds. As species start to disappear, the complex web of species interrelationships, vital for the maintenance of tropical forest biodiversity, begins to unravel. Plants loose their pollinators or seed dispersers and cannot reproduce; herbivore populations, formerly held in check by predators, expand and threaten the survival of their food plants. As key species die out, a cascade of extinctions reduces the rich biodiversity of tropical forests to a few, common weedy species that dominate the landscape. Thus, devastation of Earth's tropical forests is causing the extinction of more species now than at any time during our planet's history (Wilson, 1992).

The biodiversity of tropical forests provides a wealth of products to local communities, such as medicinal and edible plants, honey, bamboo, mushrooms and so on. Provided they are harvested sustainably, these goods can provide a valuable, long-term contribution towards the livelihoods of local people. However, because such subsistence products are not bought or sold in markets, their value is not included in indices of economic development (*e.g.* gross domestic product). Hence, their importance is largely ignored by policy makers, who sacrifice forests for conversion to other uses. Consequently, poverty worsens, when local people are forced to buy substitutes for lost forest products with cash, whilst paradoxically, economic indices show a false increase in national prosperity.

Tropical forests also provide vital ecological services that maintain environmental stability. Predators that live in forests can control pests in surrounding farmland,

Forests provide a vast array of products to local people.



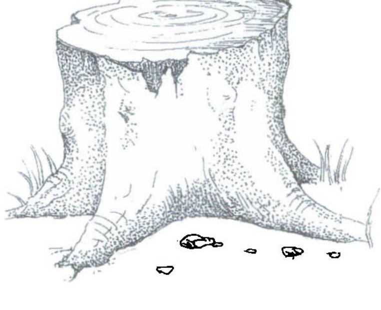


Deforestation causes soil erosion, floods and landslides.

whilst forest-dwelling bats and insects pollinate many crops, especially fruit trees. The huge quantities of leaf litter, produced by mature tropical forests, create deep organic-matter-rich soils, which store vast amounts of water per unit volume. These soils soak up water during the rainy season, preventing floods. Conversely, in the dry season, water slowly drains out of forest soils, maintaining stream flow and thus averting droughts. Furthermore, forests help to reduce global warming, by absorbing vast quantities of carbon dioxide into their canopies and converting it into wood.

All these products and ecological services represent a substantial contribution to the quality of Human life, yet all are threatened by deforestation.

A tree stump symbolises forest destruction...



How fast are tropical forests disappearing?

The Food and Agriculture Organization of the United Nations provides the most comprehensive assessments of tropical forest cover, using satellite imagery. Worldwide, the area of natural tropical forests[1] declined from 1,945 to 1,803 million hectares between 1990 and 2000 AD. Ten million hectares were converted into tree plantations, whilst 142 million hectares were converted to other land uses. Over the same period, only about 10 million hectares of deforested land regenerated into tropical forest. The net annual average reduction in natural tropical forest cover was, therefore, 14.2 million hectares (approximately 0.7 percent per year), about the same rate of decline as during the previous 10 years; 1980-90 (FAO, 2001).

In Thailand, natural forests covered 9.8 million ha (19.3 percent of the country's area) in 2000 AD. Despite a ban on commercial logging since 1989, the average annual reduction in natural forest cover (1995-2000) remained 0.26 million hectares (2.3 percent of the 1995 figure) (FAO, 1997, 2001). Overall, since 1961, Thailand has lost nearly two thirds of its forests (Bhumibamon, 1986).

[1]Tree cover >10%, not including plantations.

Section 2 – Forest Restoration - Confronting the Crisis

Can tropical deforestation and the associated catastrophic losses of biodiversity be reversed? Or is merely slowing the rate of devastation the best that conservationists can realistically hope for? Fortunately, forests have a tremendous natural capacity for self-recovery. Under natural conditions, recovery can take centuries but, by understanding and enhancing the natural processes of forest regeneration, it can be completed in just a few years. The simple techniques, described in this book, show how this can be done. ***Restoration of tropical forests is no longer a pipedream but a realistically achievable goal.***

What is the difference between reforestation and forest restoration?

"Reforestation" means the re-establishment of any kind of tree cover on deforested land. It is a broad term, encompassing various forms of forestry with different objectives, such as plantations, agro-forestry, community forestry and so on. In the tropics, commercial tree plantations are the most common forms of reforestation. Asia leads the world in this type of reforestation. By 2000, 62 percent of the world's tree plantations were located there; contributing 20 percent to Asia's total tree cover. Thailand ranks 8th among countries with the largest proportion of the world's tree plantations. Nearly 5 million hectares of mostly pine, eucalypt and rubber plantations constitute about one third of Thailand's total tree cover (FAO, 2001).

Such plantations are needed to satisfy the growing demand for wood and pulp and they may reduce the need to log natural forests. However, they do not provide suitable habitat for the plant and animal species that once inhabited the forest ecosystems that plantations replace.

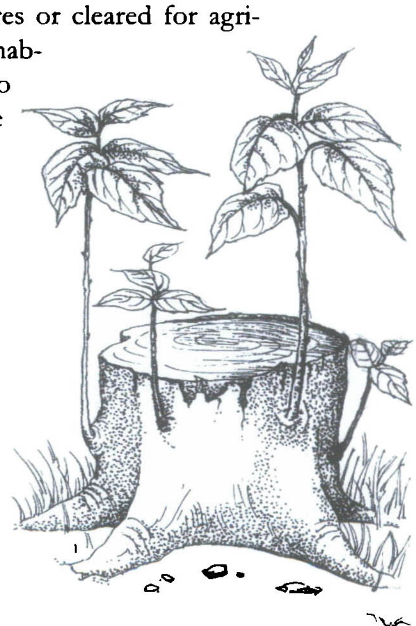
For environmental protection and conservation of biodiversity, "forest restoration" is more appropriate. It is defined as "re-establishment of the original forest ecosystem that was present before deforestation occurred".

Forest restoration cannot re-establish all plant and animal species that lived in the original forest in a single step, since in most areas, the complete flora and fauna of the original forest are unknown. Rather, it aims to restore former levels of ecosystem structure and functioning, by planting key tree species that played a vital role in the ecology of the original forest. The success of forest restoration can be measured in terms of the return of a multi-layered canopy; increasing numbers of returning species (particularly rare or keystone species); improved soil conditions and so on. Therefore, forest restoration is a specialized form of reforestation (Elliott, 2000).

Where is forest restoration appropriate?

Forest restoration is appropriate wherever biodiversity is one of the goals of reforestation, such as for wildlife conservation, environmental protection, eco-tourism or to supply a wide variety of forest products to local communities. It is most suitable for reforesting degraded sites within protected areas. Since the 1960's, the Royal Forest Department[1] (RFD) has declared 138 national parks or wildlife sanctuaries, covering more than 15 percent of the country (Elliott & Cubitt, 2001).

However, even these conservation areas often contain large deforested sites, logged by former concessionaires or cleared for agriculture by former inhabitants. If they are to fulfill their role as the last refuges for Thailand's wildlife, forest restoration, as defined above, is urgently needed.



...but some tree stumps can spring back to life.

[1]Now the Department of National Parks and Wild Plants and Animals (DNP)

Anyone can enjoy the satisfaction of planting trees...

Is tree planting essential to restore forest ecosystems?

A lot can be achieved by studying how forests regenerate (see Part 3). The factors that limit regeneration can be identified and consequently, various interventions can be implemented to overcome them. These can include weeding and adding fertilizer around natural tree seedlings, preventing fire, removing cattle and so on.

This is termed "accelerated natural regeneration" or ANR (see Part 4). ANR is simple and cost-effective, but it usually operates on trees that are already present. These usually represent only a small fraction of the total tree species that comprise mature tropical forests. Therefore, for full recovery of biodiversity, some tree planting is usually necessary. It is not feasible to plant all the many hundreds of trees that may formerly have grown in the original forest and, fortunately, it is also unnecessary.

What is the framework species method of forest restoration?

Planting a few, carefully selected tree species can rapidly re-establish forest ecosystems with high biodiversity. First developed in Queensland, Australia (Goosem and Tucker, 1995; Lamb *et al.*, 1997; Tucker and Murphy, 1997; Tucker, 2000), the framework species method involves planting mixtures of 20-30 indigenous forest tree species that rapidly re-establish forest structure and ecosystem functioning. Wild animals, attracted by the planted trees, disperse the seeds of additional tree species into planted areas, whilst the cooler, more humid and weed-free conditions, created by the planted trees, favor seed germination and seedling establishment (see Part 5).

Excellent results were achieved with this method in Australia (Tucker and Murphy, 1997), but could this success be replicated in Thailand? Chiang Mai University's Forest Restoration Research Unit was founded in 1994 to address this question.

...but it is also important to monitor the performance of planted trees, to learn from mistakes and improve techniques year by year.

Section 3 - The Forest Restoration Research Unit

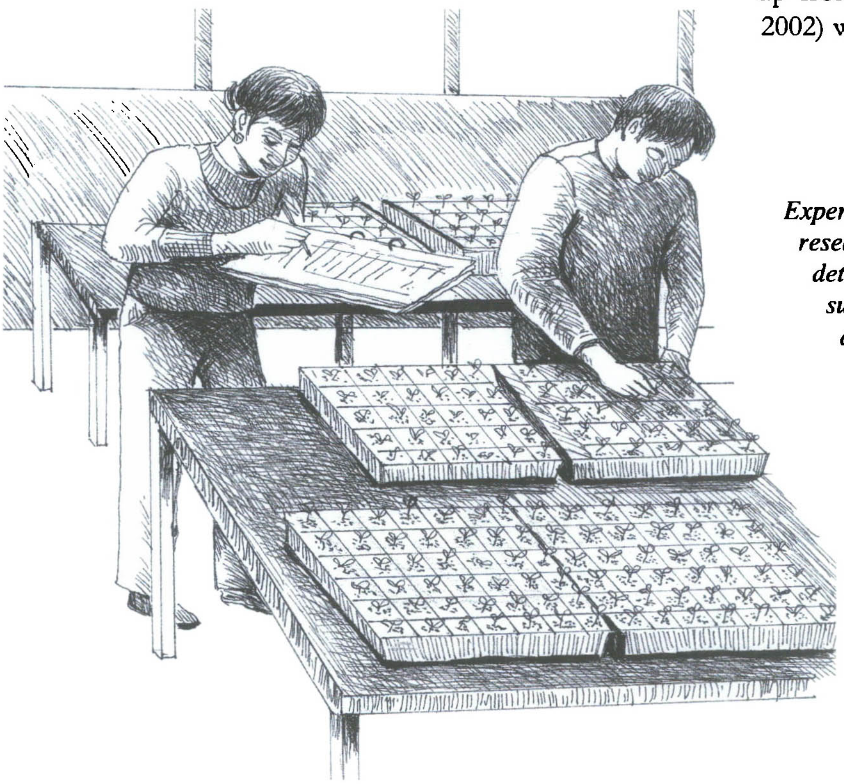
In 1994, a few members of staff and students of the Biology Department, in Chiang Mai University's (CMU) Science Faculty, started to investigate the possibility of restoring forests on degraded sites in northern Thailand, by adapting the framework species method to local conditions. With a founding grant from Riche Monde (Bangkok) Ltd., and technical assistance from Bath University, U.K. (sponsored by The British Council), a research facility was established in collaboration with Doi Suthep-Pui National Park authority (under the DNP) and named the Forest Restoration Research Unit (FORRU-CMU). It now consists of an office and research tree nursery at the park headquarters, a community nursery and field plots at Ban Mae Sa Mai and an education unit, in the Herbarium Building of CMU's Biology Department.

What kind of research has FORRU-CMU carried out?

The techniques and recommendations described in this book are derived from 10 years of research, carried out by both FORRU staff and research students of CMU's Biology Department.

FORRU's first task was to screen some of the more than 660 tree species that are indigenous to the national park (Maxwell and Elliott, 2001) for their ability to act as framework species. Forest restoration begins with seed collection, so FORRU's researchers labeled trees of more than 100 species in the forest around the research station and observed them every 3 weeks, over four years for flowering and fruit production. This study revealed seasonal patterns of fruiting, enabling seed collection schedules to be devised.

The success of any forest restoration project depends on the production of top quality planting stock. Therefore, in the nursery, experiments were designed to develop horticultural practices that optimize seed germination and seedling vigor and health (Blakesley *et al.*, 2000). Germination trials were carried out on more than 400 native forest tree species (Blakesley *et al.*, 2002). Some species germinated easily, whilst others proved difficult. So various treatments to break dormancy were tested, including scarification, heat treatments and soaking in water and acid (Kopachon, 1995; Singpetch, 2001; Vongkamjan, 2003). For those species that proved difficult to grow from seed, vegetative propagation from cuttings (Vongkamjan, 2003) and the nurturing of seedlings dug up from the forest (Kuarak, 2002) were also investigated.



Experiments at FORRU's research nursery have determined the effects of sun and shade on seed dormancy and germination of more than 400 indigenous forest tree species.

FORRU's researchers follow seedling performance from seed germination to planting.

Experiments were then conducted to determine the best container types and media for seedling growth and survival (Zangkum, 1998; Jitlam, 2001). Various methods of fertilizer application and pruning were also tested.

Different tree species produce seeds at different times of the year and seedling growth rates also vary among species, yet all species must grow big enough for planting by the beginning of the rainy season. Therefore, one of the main aims of research in the nursery was to identify treatment combinations that produce trees of a plantable size and quality by the first or second planting season after seed collection (see Part 6).

This led to the development of production schedules for many tree species, which can be used by nursery managers to formulate effective nursery production programmes for mixed crops of framework tree species (Kuarak *et al.*, 2000; Elliott *et al.*, 2002; Blakesley *et al.*, 2000).

Trees were planted out in field trials to assess the relative performance of various "potential" framework species (Elliott *et al.*, 2003). Survival and growth were monitored, as well as ability to shade out weeds and resilience to fire. Various silvicultural treatments, to enhance performance of the planted trees were also tested. These included different weeding methods, mulching and fertilizer application regimes (Elliott *et al.*, 2000) (see Part 7).

An essential characteristic of framework tree species is attractiveness to seed-dispersing wildlife. Therefore, planted trees were checked regularly for production of any resources that might attract birds or mammals (*e.g.* fruits, flowers *etc.*). Surveys to assess the species richness and composition of the ground flora (Khopai, 2000) and bird and mammal communities were also carried out ((Chantong, 1999; Toktang 2005; Thaiying, 2003).

One of the most important outcomes of FORRU's research has been identification of species that can rapidly restore forest structure and function (Elliott *et al.*, 2003), whilst enhancing forest regeneration and biodiversity recovery. Part 9 describes such framework species and explains how to grow them.

Tree growing techniques developed by FORRU's research program are tested for practicability in a community nursery by local people.

Does FORRU-CMU work with local communities?

The ultimate test of FORRU's work is whether local people can accept and use the new techniques developed by the project. As well as sound techniques, based on scientific research, forest restoration requires considerable sustained commitment in terms of time, labour and financial inputs from all those involved. Forest restoration programs can only succeed if local authorities and communities understand the benefits of ecosystem recovery and are motivated to maintain their commitment over several years.

To investigate these aspects of forest restoration, FORRU-CMU developed a close partnership with a local community, Ban Mae Sa Mai, the largest community of Hmong hill-tribe people in northern Thailand. FORRU-CMU worked with the villagers to establish experimental field trials in the watershed above the village. The story of how FORRU-CMU and the extraordinary community of Ban Mae Sa Mai combined the needs of science with those of local people is told in Part 8.

FORRU-CMU helped the villagers to build and manage their own tree nursery. As well as producing all the trees needed for forest restoration within the Mae Sa Valley, this nursery also serves as a test bed, where villagers with no scientific background, test the new propagation techniques developed by FORRU's research.

By developing this model with a local community, FORRU-CMU has been able to gain valuable insights into the logistics of implementing forest restoration projects. Much of that knowledge is presented in Part 8.

Furthermore, the nursery and plots at Ban Mae Sa Mai are providing a valuable demonstration model for training and education. As news of the project's success spread, a growing stream of visitors came to learn from the results. FORRU's research staff soon became overwhelmed by the burgeoning demand for education and training services, so a new branch of the project was created to implement a comprehensive education program.

In 2001, FORRU-CMU, the villagers of Ban Mae Sa Mai and local RFD staff won an award for good tree care from the Royal Forest Department.

Section 4 - Education and Training for Restoring Tropical Forest Biodiversity

In 2002, FORRU-CMU and its UK partner, East Malling Research (EMR, formerly Horticulture Research International), were awarded a grant by the U.K.'s Darwin Initiative to run a 3-year project entitled "Education and training for restoring tropical forest biodiversity". This enabled employment of a full-time team of educators to disseminate FORRU's research results through a schools program, workshops and extension services. This manual is one of the outputs of that project.

It makes available, to all those interested in restoring forest ecosystems, techniques that have been scientifically developed by FORRU-CMU and tested for their practicability in a local community. Draft copies were trialed and improved by NGO's, government agencies, school teachers and community groups at several workshops run during the project.

What are the aims of this manual?

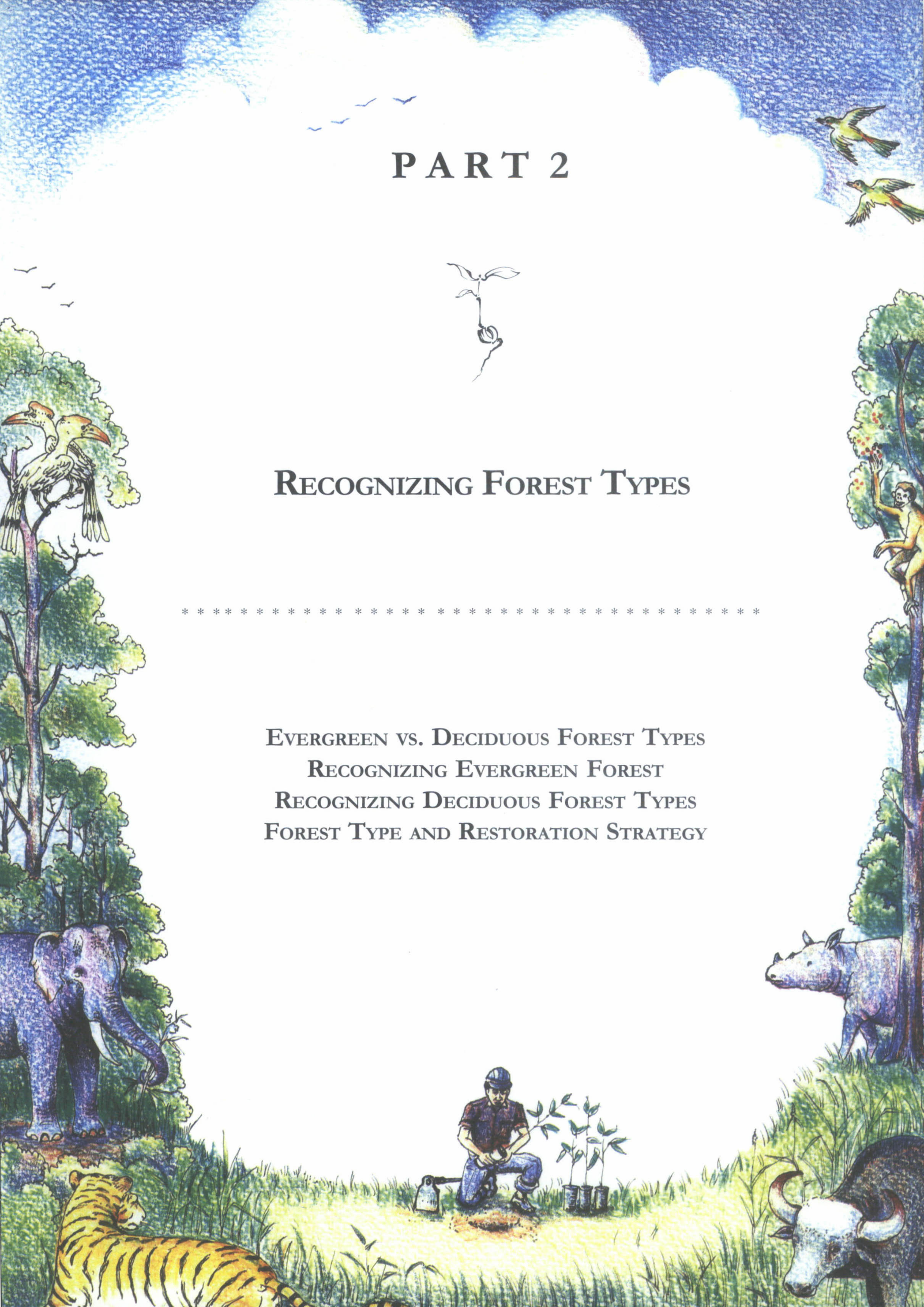
It presents the basic principles and techniques of forest restoration in an accessible format for all organizations committed to restoring tropical forest ecosystems. In particular, it explores the development of the framework species method in northern Thailand, and describes confirmed framework species for that region (see Part 9). However, this manual is not solely for Thai organizations. The approach that FORRU-CMU has developed can be adapted and applied to other regions.

Whilst many publications have been produced on the various forms of economic forestry, they often ignore the role of forests as repositories of biodiversity and providers of ecological services. This manual aims to redress this deficiency. Its central theme is the restoration of natural forest ecosystems, primarily for biodiversity conservation and environmental protection. However, it does not ignore the economic value of forest resources. Much of its content is applicable to economic forestry such as community forestry, agro-forestry and so on. The methods described in Parts 6 & 7 should encourage more efficient tree husbandry for all forms of forestry. Many of the framework species, described in Part 9, also have uses in agro-forestry or community forestry. Several have exceptionally high growth rates and should be further investigated for their potential as plantation species. Even where commercial objectives are paramount; the concepts and methods described here provide a means to integrate biodiversity conservation into forest management plans, particularly the diversification of plantation forestry.

A common view is that forest destruction is the inevitable consequence of human population growth and economic development. We fundamentally disagree with this pessimistic outlook. ***Deforestation can be reversed*** with better technical expertise, greater understanding of the value of forests and more incentives to encourage forest restoration.

We, therefore, hope that this text will contribute towards a more optimistic outlook for the world's tropical forests.

FORRU's nursery in Doi-Suthep-Pui National Park serves as a classroom, as well as a research facility.



PART 2

Recognizing Forest Types

* *

Evergreen vs. Deciduous Forest Types
Recognizing Evergreen Forest
Recognizing Deciduous Forest Types
Forest Type and Restoration Strategy

Evergreen Forest (EGF)

Above 1,000 m elevation, evergreen forests are rich in biodiversity and protect watersheds. Lack of light limits plant growth beneath the dense canopy.

Magnolias are typical of evergreen forest. The fruit above is Manglietia garrettii.

Understorey shrubs, like Phlogacanthus curviflorus *(below) are shade tolerant, to survive beneath the forest canopy.*

Epiphytes like Aeschynanthus hosseusii *(above) reach the light by growing in the forest canopy.*

Sapria himalayana *(left) needs no light. It extracts nutriment from the roots of lianas (*Tetrastigma *spp).*

Rhododendron vietchianum *(right) is an epiphytic shrub.*

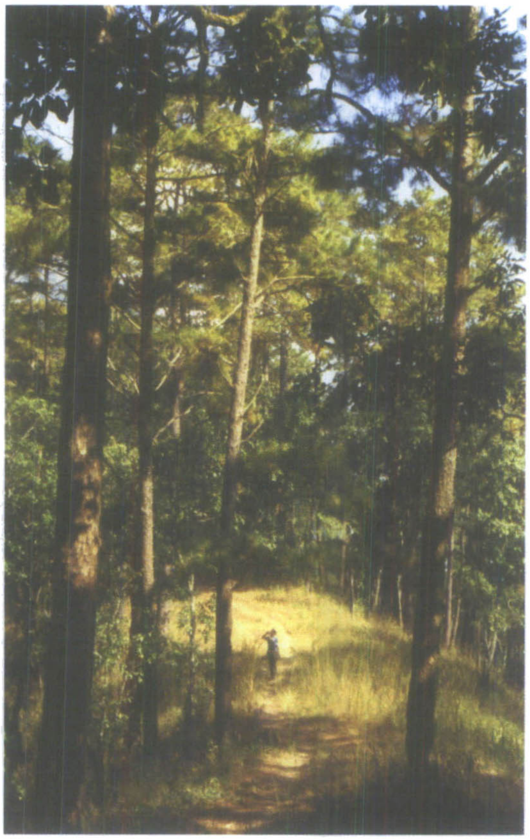
Evergreen Forest with Pine (EG-PINE)

Along fire-prone ridges, above 1,000 m elevation, pines can dominate evergreen forest. Below are a few species, which typically grow with pines.

Hacking kindling wood and resin tapping are destroying Thailand's native pines (above). The trees become weakened and are easily blown over by gales.

Many species of oak or chestnut (Fagaceae) grow alongside pines. Above is Castanopsis argyrophylla.

Impatiens violaeflora *(above) flowers from August to November amongst the ground flora of EG-PINE.*



EG-PINE, Doi Chiang Dhao, 1,200 m elevation.

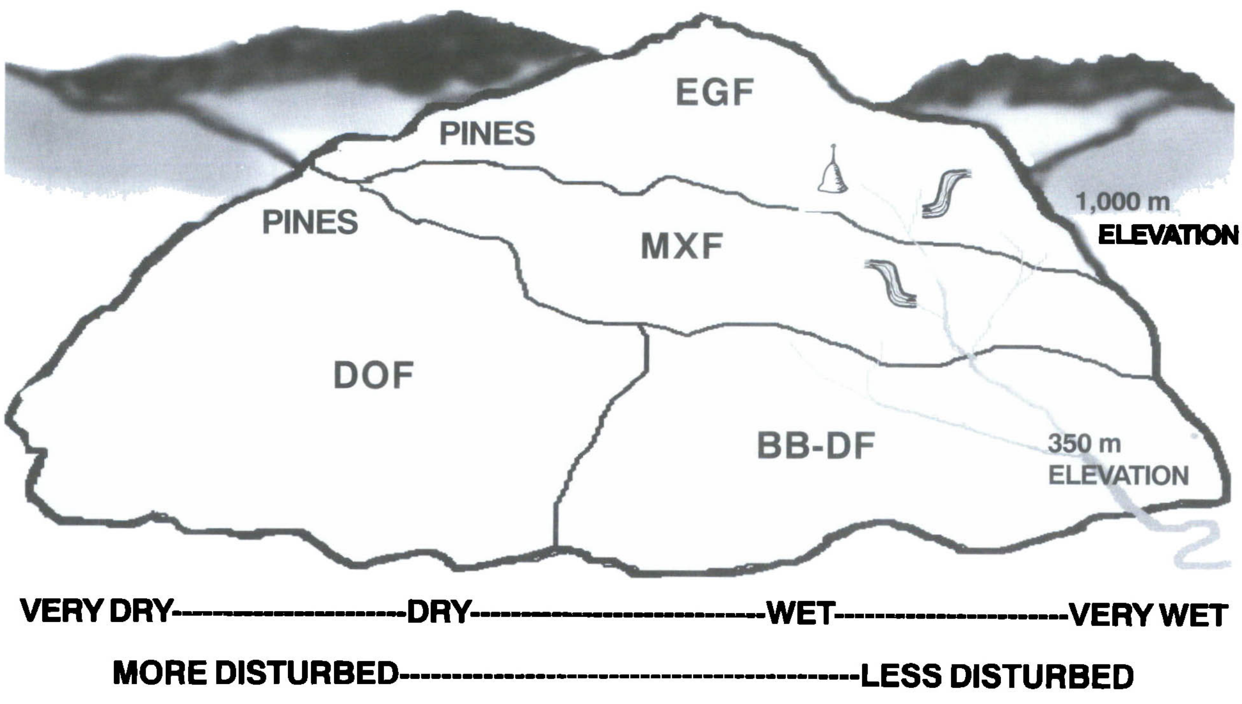
RECOGNIZING FOREST TYPES

When India gradually began to collide with the rest of Asia around 50 million years ago, the event not only threw up the mighty Himalayan Mountains, but also a tail of lesser mountains swirling away to the east and south. This geological incident provided northern Thailand with its main topographical features: broad valleys, separated by steep mountain ridges orientated very approximately north to south, with elevations ranging from 300 m in valley bottoms to 2,565 m at the summit of Thailand's highest mountain, Doi Inthanon. Such varied topography created a wide range of different physical conditions. As a result, the northern region supports a greater variety of forest types, in close proximity to each another, than any other part of the country. This diversity of forest types provides a wide range of wildlife habitats. Consequently, the region supports remarkably high biodiversity. The northern mountains are home to at least 150 mammal species and 383 bird species. Chiang Mai University's Herbarium holds records for >3,500 vascular plant species from the north, of which >1,120 are trees. Although adjacent forest types may have many species in common, each also has unique characteristics, which must be taken into consideration when planning forest restoration.

Why is it important to recognize forest types?

Forest restoration directs and accelerates natural forest succession in order to recreate original forest ecosystems as closely as possible. The original forest type, therefore, defines the goal of the activity. Consequently, identification of the original forest type is critical when planning forest restoration projects. It determines which tree species must be grown in nurseries and which trees are planted on each particular site to be restored. So, wherever biodiversity conservation is a major management priority, the composition of original forest provides a bench mark, against which progress and the ultimate success of forest restoration are measured.

Diagramatic representation of the distribution of main forest types on a typical mountain in northern Thailand. EGF = Evergreen Forest; MXF = Mixed Evergreen-Deciduous Forest; BB-DF = Bamboo-Deciduous Forest (former Teak Forest); DOF = Deciduous Dipterocarp-Oak Forest (after Maxwell and Elliott (2001)).



SECTION 1 – EVERGREEN VS. DECIDUOUS FOREST TYPES

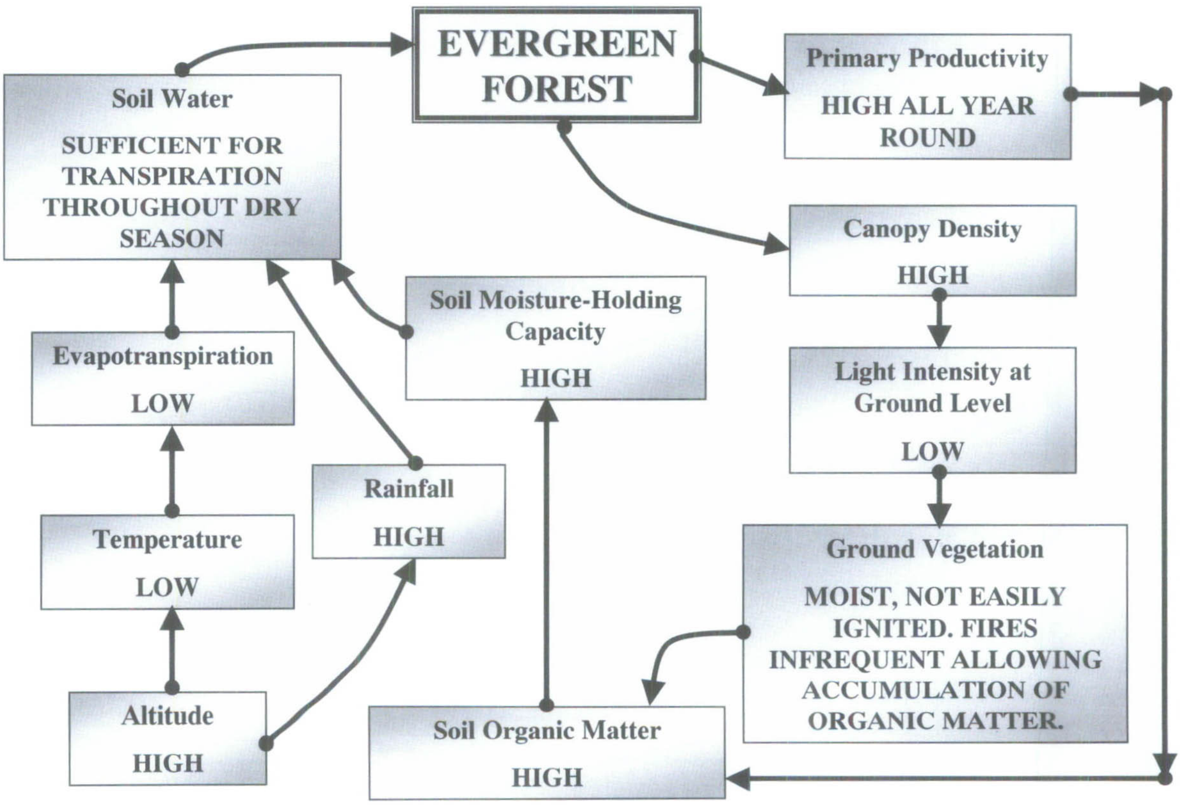
The forests of northern Thailand can be broadly divided into evergreen and deciduous types, with evergreen forests growing above (very) roughly 1,000 m elevation and deciduous forests growing lower down. Soil moisture is the over-riding factor that determines the distribution of these two broad categories of forest type.

In seasonally-dry, tropical environments, trees shed their leaves to survive drought during the dry season. Evergreen forests grow where soil moisture is sufficient to meet the transpiration needs of the trees throughout the year, whereas deciduous forests grow where soil moisture falls below that needed to maintain transpiration during the dry season.

Within all plants, there is usually a constant, upward flow of water, transporting nutrients from the roots to the leaves. This is transpiration and it is driven by evaporation of water from cells within the leaves and diffusion of water vapour into the atmosphere via pores in the leaves' surfaces, called stomata. When soil moisture falls below the level needed to support transpiration for long periods, trees may shed their leaves. This prevents water loss and retains sufficient water within roots, trunks and branches to maintain basic metabolism, until the rains replenish soil moisture.

Therefore, the amount of moisture retained in the soil by the beginning of the dry season is the critical factor that determines whether a forest is evergreen or deciduous - and that, in turn, is primarily determined by elevation. Trees cannot respond directly to elevation, but they do respond to the impact of elevation on soil moisture.

Rainfall increases with increasing elevation. As warm air (which can hold a lot of water vapour) passes over mountains, it is forced up into cooler air. Since cool air can hold less water vapour than warm air, some of the vapour must condense out as rain (orographic precipitation). In contrast, temperatures fall with increasing elevation (approximately -0.6 °C for every 100 metres ascended) and consequently, losses of water from the soil and through the vegetation by evaporation also decline. So, at high eleva-tions, more water enters the soil from rainfall and less is removed by evaporation.

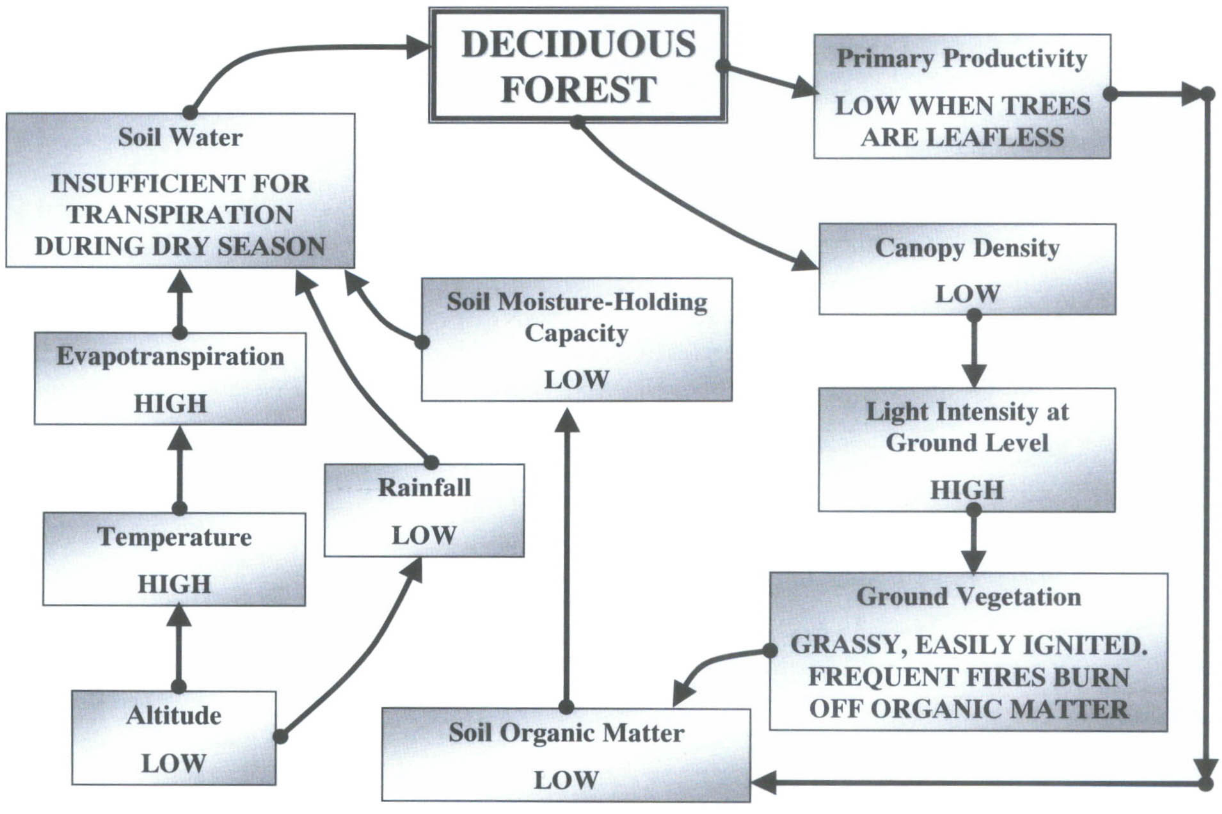


Furthermore, evergreen forest soils are rich in organic matter (due to a continuous rain of leaf litter from the highly productive trees). High organic matter content greatly enhances the moisture-holding capacity of the soil. In evergreen forests, "field capacity" (the maximum amount of water that can be held within 1 gm of dry soil) averages typically about 0.35 gm water per gm of dry soil; enough to feed the transpiration needs of the trees throughout the dry season. Therefore, most of the tree species at higher elevations can retain dense foliage all year round, without drying out.

In the lowlands, everything is reversed. Less water enters the soil (due to lower rainfall); evaporation is higher (due to higher temperatures) and soil field capacity is lower (averaging only about 0.20 gm water per gm of dry soil), especially if fire burns off organic matter. Therefore, even if the soil reaches field capacity by the end of the rainy season, it retains insufficient moisture to maintain transpiration of the trees throughout the dry season. The trees shed their leaves, effectively shutting down transpiration and conserving water for survival.

Superimposed on the effects of elevation, disturbances caused by humans have a modifying effect on the distribution of forest types. Such disturbances also exert their effects mostly by reducing soil moisture. Tree felling, browsing by cattle and agricultural activities open up the forest canopy, causing the soil to dry out, leading to soil erosion and reduced plant growth. Fire burns off soil organic matter, whilst reduced primary production reduces inputs of organic matter into the soil. Reduced soil organic matter content inevitably leads to reduced soil moisture-holding capacity, opening the way for deciduous trees to invade areas above 1,000 m, previously occupied by evergreen forest. Conversely, evergreen forests can sometimes spread down to lower elevations, along streams or wherever soil moisture is high. However, due to logging in the past, lowland evergreen forests have been completely eliminated from northern Thailand.

Other factors such as bedrock, aspect and slope can also affect the distribution of forest types, but none of these is as influential as soil moisture.



Section 2 – Recognizing Evergreen Forest

Whilst evergreen forests in northern Thailand are fairly uniform, deciduous forests can be divided into at least 3 distinct types. In Sections 2 & 3, we present a summary of the most characteristic features of northern Thailand's main forest types, adapted from Maxwell and Elliott's (2001) analysis of the vegetation of Doi Suthep-Pui National Park (see also Maxwell, 2004).

What are the distinguishing characteristics of evergreen forest (EGF)?

In northern Thailand, evergreen forest (EGF) grows above 1,000 m elevation or slightly lower along streams. Floristically, EGF is quite uniform, and cannot be divided into sub-types, up to the maximum elevation in the region (Doi Inthanon summit 2,565 m).

EGF is quite distinct from the various deciduous forest types. The main canopy, often with emergent tree crowns, is much higher and denser than that of deciduous forests, often exceeding 30 m in height. This creates dense shade at ground level. Beneath the main canopy, the lower story is comprised of young trees, treelets and shrubs. Woody climbers and fig trees are common.

A high abundance of epiphytes is an obvious feature of EGF. In addition to vascular plants, algae, bryophytes and lichens often encrust tree trunks and branches.

The ground flora is often dense and consists of tree seedlings and herbs, including several with a saprophytic or parasitic way of life. Grasses can occur in disturbed areas, but tall bamboos are absent.

Fires are less common in EGF than in deciduous forests, but when fire does occur, it is much more damaging, since EGF trees lack the resilience of deciduous forest trees. After a fire, shrubs, the ground flora and populations of ground-dwelling small mammals and birds may take many years to recover.

High biodiversity is a feature of EGF. More tree species grow there than in any other forest type (at least 250 have been recorded so far). Although no tree species or genus dominates, several families tend to be better represented in EGF than in the deciduous forest types *e.g.* Lauraceae, Fagaceae, Theaceae, Moraceae, Magnoliaceae, *etc.* Most of the canopy trees are evergreen. Characteristic ones include *Lindera caudata* (Nees) Bth. and *Phoebe laceolata* (Wall. *ex* Nees) Nees (both Lauraceae), *Artocarpus lanceolata* Trec. and several gigantic "strangling" figs, *e.g. Ficus altissima* Bl. and *F. benjamina* L. (Moraceae). Of the oaks (Fagaceae), *Quercus vestita* Rehd. & Wils., *Q. glabricupula* Barn., *Q. incana* Roxb. and *Q. lineata* Bl. are all highly characteristic. Other characteristic evergreen trees include *Pyrenaria garrettiana* Craib (Theaceae), *Garcinia mckeaniana* Craib (Guttiferae), *Casearia grewiifolia* Vent. (Flacourtiaceae), *Chionanthus sutepensis* (Kerr) Kiew (Oleaceae), *Elaeocarpus prunifolius* Wall. *ex* C. Muell. (Elaeocarpaceae), *Dysoxylum excelsum* Bl. (Meliaceae), *Ostodes paniculata* Bl. (Euphorbiaceae) and *Diospyros marlabarica* Cl. (Ebenaceae).

Despite the name of this forest type, about 27% of its tree species are deciduous, although many of these are also shared with MXF. A few of the larger deciduous canopy species include *Manglietia garrettii* Craib and *Magnolia baillonii* Pierre (both Magnoliaceae), *Melia toosendan* Sieb. & Zucc. (Meliaceae) and *Morus macroura* Miq. (Moraceae). Some deciduous trees, restricted to evergreen forest, include *Acrocarpus fraxinifolius* Wight *ex.* Arn. (Leguminosae, Caesalpinioideae), *Litsea zeylanica* (Nees) Nees (Lauraceae) and the rather rare *Hovenia dulcis* Thunb. (Rhamnaceae),

The understorey is denser than that of deciduous forests and is very diverse in stream valleys. Understorey trees include: *Phoebe lanceolata* (Nees) Nees (Lauraceae), *Acronychia pedunculata* (L.) Miq. (Rutaceae), *Sarcosperma arboreum* Bth. (Sapotaceae) and *Diospyros glandulosa* Lace (Ebenaceae). Deciduous representatives include *Engelhardia spicata* Lechen. (Juglandaceae) and *Spondias axillaris* Roxb. (Anacardiaceae).

Treelets and shrubs (91 and 22 recorded species, respectively) are numerous. Characteristic treelets include *Vernonia volkameriifolia* DC. (Compositae), *Glochidion kerrii* Craib (Euphorbiaceae), *Debregeasia longifolia* (Burm. f.) Wedd. (Urticaceae), *Archidendron glomeriflorum* (Kurz) Niels. (Leguminosae, Mimosoideae) and *Litsea cubeba* (Lour.) Pers. (Lauraceae). Characteristic evergreen shrubs include *Psychotria ophioxyloides*

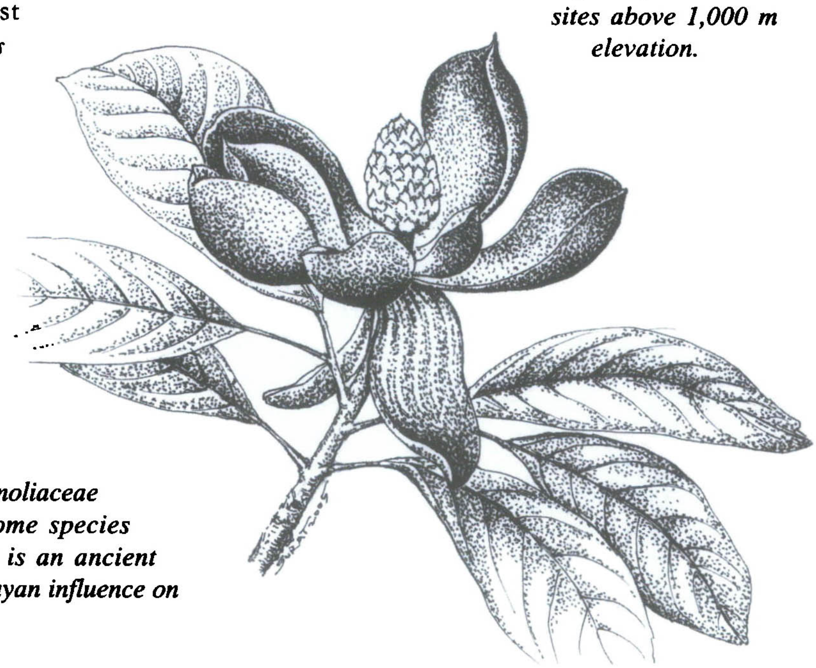
Wall. (Rubiaceae) and *Phlogacanthus curviflorus* (Wall.) Nees (Acanthaceae). Pandans and banana plants (*e.g. Pandanus penetrans* St. John (Pandanaceae) and *Musa itinerans* Cheesm. (Musaceae)) are characteristic of shaded, stream valleys.

A high diversity of woody climbers (78 recorded species) is a notable feature of evergreen forest. Some characteristic evergreen examples include: *Toddalia asiatica* (L.) Lmk. (Rutaceae), *Ficus parietalis* Bl. (Moraceae), *Combretum punctatum* Bl. (Combretaceae) and *Uncaria macrophylla* Wall. (Rubiaceae). Also common are several species of *Tetrastigma* (*e.g. T. laoticum* Gagnep. and *T. obovatum* (Laws.) Gagnep. (Vitaceae)) and *Mucuna macrocarpa* Wall. (Leguminosae, Papilionoideae), which also occur in MXF. Rattan palms are characteristic, but fairly rare, in EGF *e.g. Calamus palustris* Griff. var. *cochinchinensis* Becc. and *Plectocomia kerrana* Becc.

Epiphytes abound in evergreen forest. The 82 species recorded there include trees, shrubs, vines and herbs. The trees include the so-called "strangling" figs, which begin life as epiphytes *e.g. Ficus superba* (Miq.) Miq. (Moraceae) and the very rare *Sorbus verrucosa* (Decne.) Rehd. (Rosaceae). Characteristic epiphytic shrubs include a rhododendron (*Rhododendron vietchianum* Hk. (Ericaceae)) and several hemi-parasitic mistletoes (*e.g. Macrosolen cochinchinensis* (Lour.) Tiegh., *Viscum ovalifolium* Wall. *ex* DC. and *V. orientale* Willd. (Loranthaceae)). Epiphytic herbs are nearly all perennials and many are deciduous. Species particularly characteristic of evergreen forest include ferns (*e.g. Lepisorus nudus* (Hk.) Ching (Polypodiaceae) and *Davallodes membranulosum* (Hk.) Copel. (Davalliaceae)); gingers (*e.g. Hedychium ellipticum* Ham. *ex* J. Sm.); orchids (*e.g. Bulbophyllum bittnerianum* Schltr., *Coelogyne schultesii* Jain & Das. and *Trichotosia dasyphylla* (Par. & Rchb. f.) Krzl. and gesnerids (*e.g. Didymocarpus wattianus* Craib and *Aeschynanthus hosseusii* Pell. (Gesneriaceae)).

The herbaceous ground flora (321 recorded species) is very diverse. Characteristic ferns in shaded undisturbed areas include *Arachnoides henryi* (Christ) Ching and *Tectaria herpetocaulos* Holtt. (both Dryopteridaceae), *Thelypteris subelata* (Bak.) K. Iw. (Thelypteridaceae) and *Diplazium dilatatum* Bl. (Athyriaceae). Common flowering herbs in EGF include: *Impatiens violaeflora* Hk. f. (Balsaminaceae), *Opiorrhiza trichocarpon* Bl. and *Geophila repens* (L.) I.M. John. (both Rubiaceae) and *Pilea trinervia* Wight (Utricaceae). Gingers such as *Globba kerrii* Craib, *G. villosula* Gagnep. and *Zingiber smilesianum* Craib (Zingiberaceae) are also common.

Some plants in the ground layer of EGF lack the need for light for photosysnthesis because they have evolved a parasitic or saprophytic way of living. For example *Balanophora* species superficially resemble fungi (*e.g. B. abbreviata* Bl. and *B. fungosa* J.R. & G. Forst.) but are parasitic on tree roots. *Sapria himalayana* Griff. (Rafflesiaceae) is the most spectacular parasite, with bright red flowers, the size of saucers, with yellow spots. It parasitizes the roots of woody climbers in the genus *Tetrastigma* (Vitaceae).



Manglietia garrettii ***Craib (Magnoliaceae) is a framework tree species, recommended for including in forest restoration plantings on former EGF sites above 1,000 m elevation.***

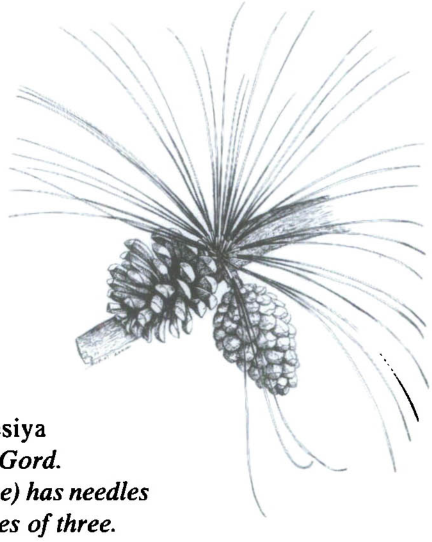
The tree and shrub family Magnoliaceae is typical of EGF (although some species occasionally grow in MXF). It is an ancient family and represents the Himalayan influence on northern Thailand's flora.

What are the distinguishing characteristics of pine forest (EGF-PINE)?

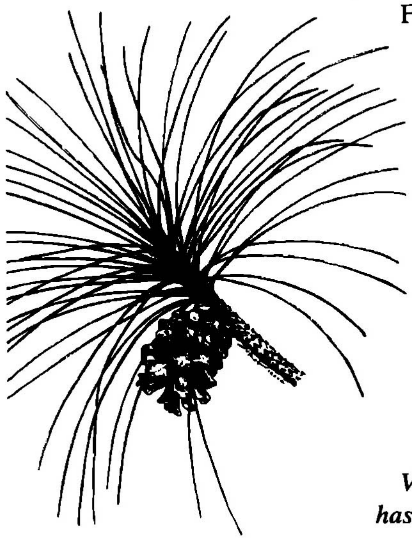
On fire-prone, exposed ridges at elevations of about 950-1,800 m the pine tree, *Pinus kesiya* Roy. *ex* Gord. (Pinaceae) may grow in abundance, amongst other EGF tree species; in some places dominating the forest. At the lower elevation limits of EGF, Thailand's other, much less common pine species, *Pinus merkusii* Jungh & De Vriese may also grow.

The canopy of evergreen forest with pine (EGF-PINE) is more open than that of EGF without pine. Several oak or chestnut species (Fagaceae) are characteristically associated with pines, including *Castanopsis argyrophylla* King *ex* Hk. f., *Quercus brandisiana* Kurz, *Q. leticellata* Barn. and *Lithocarpus craibianus* Barn (Fagaceae). Other tree species, associated with pines (mostly due to the lower pH of the soil), include *Viburnum inopinatum* Craib (Caprifoliaceae), *Helicia nilagirica* Bedd. (Proteaceae) and *Myrica esculenta* B.-H. *ex* D. Don (Myricaceae).

Where fires are particularly frequent, trees more characteristic of deciduous dipterocarp-oak forest can spread up into EGF-PINE and grow at much higher elevations than is typical (*e.g. Craibiodendron stellatum* (Pierre) W. W. Sm. and *Vaccinium sprengelii* (D. Don) Sleum. (both Ericaceae), *Anneslea fragrans* Wall. (Theaceae) and *Aporusa villosa* (Lindl.) Baill. In such areas, oaks and chestnuts become particularly common (*e.g. Castanopsis armata* (Roxb.) Spach, *C. tribuloides* (Sm.) A. DC., *Lithocarpus elegans* (Bl) Hatus. *ex* Soep., *L. fenestratus* (Roxb.) Rehd. and *Quercus vestita* Rehd. & Wils (all Fagaceae). A total of 99 tree species have been recorded in EGF-PINE. Shrubs and woody climbers are less prominent in EGF-PINE, compared with EGF without pine.



Pinus kesiya *Roy. ex Gord. (Pinaceae) has needles in bunches of three.*



Pinus merkusii *Jungh. et de Vriese (Pinaceae) has needles in pairs.*

Characteristic vascular epiphytes (86 recorded species) include ferns, orchids, gesnerids and hemiparasitic mistletoes (Loranthaceae and Viscaceae). Common epiphytic ferns include *Drynaria propinqua* (Wall. *ex* Mett.) J. Sm. *ex* Bedd., *Lepisorus subconfluens* Ching and *Polypodium argutum* (J. Sm. *ex* Hk. & Grev.) Hk. (all Polypodiaceae).

Epiphytic orchids are represented by many genera (*e.g. Bulbophyllum suavissimum* Rol., *Cleisostoma fuerstenbergianum* Krzl., *Coelogyne trinervis* Lindl., *Dendrobium heterocarpum* Lindl., *Diploprora championi* (Lindl.) Hk. f., *Oberonia pachyphylla* King & Pantl., *Pholidota articulata* Lindl. and *Trichotosia dasyphylla* (Par. & Rchb. f.) Krzl.).

Hemi-parasitic mistletoes are common, including *Macrosolen avenis* (Bl.) Dans. and *Scurrula ferruginea* (Jack) Dans. (Loranthaceae) and *Viscum ovalifolium* Wall. *ex* DC. (Viscaceae). Gesnerids, typical of EGF-PINE, include *Didymocarpus kerrii* Craib and *D. aureoglandulosus* Cl. (Gesneriaceae).

The ground flora includes 263 recorded herb species, both annuals (32%) and perennials (68%). Annual herbs include: *Blumeopsis flava* (DC.) Gagnep. and *Anaphalis margaritacea* (L.) Bth. & Hk. f. (both Compositae), *Lobeia nicotianaefolia* Roth *ex* Roem. & Schult. (Campanulaceae) and *Exacum pteranthum* Wall. *ex* Colebr. (Gentianaceae). Typical deciduous, perennial herbs include *Inula cappa* (Ham. *ex* D. Don) DC. (Compositae), *Pratia begoniifolia* (Wall. *ex* Roxb.) Lindl. (Campanulaceae), *Anthogonium gracile* Wall. *ex* Lindl. (Orchidaceae), *Oleandra undulata* (Willd.) Ching (Oleandraceae) and *Kuniwatsukia cuspidata* (Bedd.) Pic.-Ser. (Athyriaceae).

What are the challenges when restoring EGF and EGF-PINE?

Because EGF supports more tree species than the other forest types (see Box 2.5), tree planting should aim to include as many species as possible, within practical limits, to "kick-start" biodiversity recovery. A large proportion of evergreen forest trees have large seeds, which are dispersed by large animals *e.g.* rhinos, elephants, wild cattle *etc.* Most such large animal species have been extirpated from northern Thailand or remain only as tiny, isolated populations. Therefore, including tree species with large fleshy fruits amongst those planted can help to conserve such tree species, which now have very limited natural opportunities for seed dispersal.

Deciduous trees, which grow in evergreen forest, often make the best framework species for accelerating biodiversity recovery after planting (*e.g. Acrocarpus fraxinifolius, Erythrina subumbrans, Gmelina arborea, Hovenia dulcis, Melia toosendan, Spondias axillaris*). Their deciduous habit makes them resistant to drought-induced stress during the first hot-dry season after planting. Therefore, they usually have high survival rates.

Soils at EGF sites are usually richer in nutrients than deciduous forest soils are, so less fertilizer may be required after tree planting. In contrast, weed growth tends to be more rapid. Weeding may, therefore, have to be carried out more frequently than in deciduous forest sites, with correspondingly higher labour costs. EGF sites at higher elevations may be above the spring line. This makes watering the trees after planting unfeasible, since access to the planting sites by water tankers is also likely to be difficult. Planting must therefore be delayed until rainfall is reliable.

To restore EGF-PINE, pines, oaks and chestnuts, suited to the elevation of the planting site, should be included amongst framework tree species planted, since they are characteristic of this forest type. Since EGF-PINE occurs in fire prone areas, particular attention must be paid to fire prevention after planting.

Box 2.1 - Looking at Thailand's two indigenous pine species

Thailand's two native pine species are easily distinguished by their leaves. The needle-like leaves of *Pinus merkusii* Jungh. de Vriese grow in pairs, whereas those of *P. kesiya* Roy. *ex* Gord. grow in bundles (fascicles) of three.

In northern Thailand, *P. merkusii* tends to grow at lower elevations (300-1,200 m) than *P. kesiya*, more commonly in DOF but sometimes at the lower limits of EG-PINE. In the lowlands it is now rare due to over-exploitation for its resin and timber. *P. kesiya* is commoner and is characterstic of EG-PINE, but it also grows at the upper limits of DOF; from 950 to 1,800 m elevation.

Both species are light demanding and fire resilient. Both are exploited for resin, but *P. merkusii* produces the highest yield (large trees up to 40 kg of pure resin per year). Damage to pines by hacking at their trunks, to remove resin-soaked slivers of wood for fire lighters, is common. It weakens the trees and eventually kills them. This practice has now beome a serious threat to pines throughout northern Thailand.

Pine seeds are wind-dispersed. Where remnant trees remain, seedlings establish easily on disturbed soil, but are intolerant of dense weeds and fire. Where pines once grew, but have been completely eliminated, consider planting them, along with framework tree species. Do not grow plantations of pure pine. They are poor wildlife habitat. Obtain pine saplings from nuseries, but make sure they have been grown from seeds from local forest (not plantations). Never select saplings of exotic pines, such as *P. carribea.* To grow pines yourself, carefully cut green or brown cones, just before they open, from local forest trees, without damaging the twigs. Store the immature green cones in shade, until they turn brown. Then, sun-dry them until they open. Shake out the seeds, remove the wings and sow seeds in germination trays in sand. Transfer 3-5 cm-tall seedlings into containers and grow them on for 1-1.5 years. Alternatively, harvest 5 to 10-cm-tall seedlings from forest, during the rainy season and grow them on in containers (Box 6.1). Dried seeds remain viable for several years.

SECTION 3 – RECOGNIZING DECIDUOUS FOREST TYPES

Three deciduous forest types are easily recognised. Mixed evergreen-deciduous forest (MXF) is a distinct zone between upland evergreen and lowland deciduous forests. Bamboo-deciduous forest (BB-DF) has largely replaced formerly dominant teak forests, due to logging, whilst deciduous dipterocarp-oak forest (DOF) grows on the driest or most disturbed lowland sites.

What are the characteristics of mixed evergreen-deciduous forest (MXF)?

In a narrow elevational band from 800 to 1,000 m (or from 600 m in stream valleys), a distinct zone occurs in between EGF and BB-DF. Mixed evergreen-deciduous forest (MXF) consists of a diverse mix of tree species from both these forest types, but it also supports many species, that grow only in this forest type.

Canopy height varies from 20 to 30 m, but emergent trees, taller than 30 m, are common. Canopy cover is usually complete, though it is less dense than in evergreen forest. Woody climbers are prominent. Epiphytes are common. Bamboos are present, but are less prevalent than in BB-DF. There is usually a dense ground layer of herbs and tree seedlings. Grasses are rare, except where fire has occurred.

Of the 217 tree species, recorded in MXF on Doi Suthep, only 43% are deciduous. There is a very strong similarity between the tree floras of MXF and BB-DF. Of the 38 tree species that are common or abundant in the former, 21 (55%) are shared with the latter. The most easily recognized evergreen canopy tree species, characteristic of this forest type, are the tall, emergent, evergreen, dipterocarps: *Dipterocarpus costatus* Gaertn. f. and *D. turbinatus* Gaertn. f. (Dipterocarpaceae). With their massive trunks, relatively small leaves and broad, umbrella-shaped crowns, these trees appear very different to the large-leaved dipterocarps of DOF.

Other common tree species in MXF include *Irvingia malayana* Oliv. *ex* Benn. (Irvingiaceae), *Mangifera caloneura* Kurz (Anacardiaceae), *Eugenia albiflora* Duth. *ex* Kurz (Myrtaceae), *Lagerstroemia cochinchinensis* Pierre (Lythraceae), *Spondias pinnata* (L. f.) Kurz (Anacardiaceae), *Terminalia mucronata* Craib & Hutch. (Combretaceae) and *Engelhardia serrata* Bl. (Juglandaceae). Common evergreen understorey trees include *Garcinia speciosa* Wall. (Guttiferae) and *Scleropyrum pentandrum* (Denn.) Mabb. (Santalaceae).

More than 60 species of woody climbers have been recorded in MXF. Characteristic ones include *Securidaca inappendiculata* Hassk. (Polygalaceae), *Tetrastigma* aff. *harmandii* Planch. (Vitaceae) and *Parameria laevigata* (Juss.) Mold. (Apocynaceae). Characteristic epiphytes include orchids (*e.g. Bulbophyllum congestum* Rol. and *B. propinquum* Krzl.), hemiparasitic mistletoes (*e.g. Helixanthera pulchra* (DC.) Dans. and *Dendrophthoe pentandra* (L.) Miq. (Loranthaceae) and ferns (*e.g. Polypodium subauriculatum* Bl. and *Pyrrosia porosa* (Wall. *ex* Presl) Hoven. (Polypodiaceae)).

The ground flora includes at least 278 herb species, as well as seedlings and saplings of trees and shrubs. Most of these species are shared with EGF or BB-DF. The few that are unique to MXF include two ground orchids (*e.g. Tainia hookeriana* King & Pantl. and *Tropidia pedunculata* Bl.), a few ferns (*e.g. Microlepia puberula* v. A. v. Ros. (Dennstaedtiaceae)), *Asplenium excisum* Presl (Aspleniaceae) and *Tectaria impressa* (Fee) Holtt. (Dryopteridaceae) and the parasite, *Balanophora laxiflora* Hemsl (Balanophoraceae) on tree roots.

What are the special challenges when restoring MXF?

MXF sites are often located on steep slopes, so access to them can present problems. As with BB-DF, large bamboos can inhibit growth and survival of planted trees, so some control of them may be necessary to allow tree establishment. Most MXF sites are near permanent streams, so watering trees after planting is usually feasible. The large dipterocarps, characteristic of this forest type, have wind-dispersed seeds. Where remnant mature trees survive, there is usually no need to plant them. However, where they are absent, consider adding indigenous dipterocarp species to the mix of framework tree species planted, to maintain the distinctive structure of MXF. Dipterocarp seedlings grow very slowly in nurseries, so start collecting seeds at least 2 years in advance.

Mixed Evergreen Deciduous Forest (MXF)

Above - A massive Dipterocarpus costatus *Gaertn. f. (Dipterocarpaceae) tree, towering over the main forest canopy: a characteristic feature of MXF.*

Right - Understorey tree, Bauhinia variegata *L. (Leguminosae, Caesalpinioideae) flowers January to March, when leafless.*

Below - With no green leaves for photosynthesis, Aeginetia indica *Roxb. (Orobanchaceae) is parasitic on plant roots.*

Below - Shade-tolerant herb, Gomphostemma strobilinum *Wall. ex Bth. (Labiatae). Variegated leaves lie flat against the soil surface.*

Bamboo-Deciduous Forest (BB-DF)

Below - Planted teak, CMU campus, nearly leafless in February.

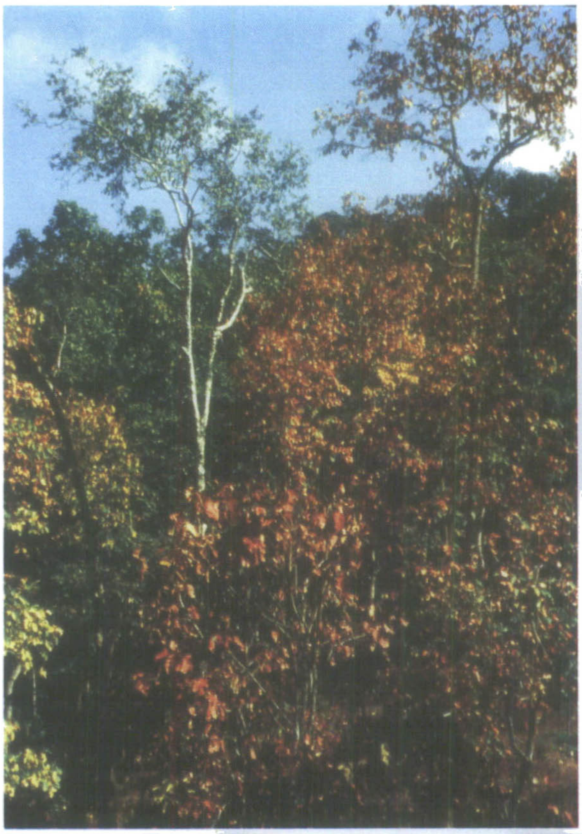
Left - Where teak has been removed, bamboos take over. Several species flower gregariously over their entire ranges.

Below- Afzelia xylocarpa *(Kurz) Craib (Leguminosae, Caesalpinioideae), a valuable timber tree in ex-teak forest.*

Insert right - Boesenbergia longiflora *(Wall.) O. K. (Zingiberaceae) adds colour to the ground flora of BB-DF, August.*

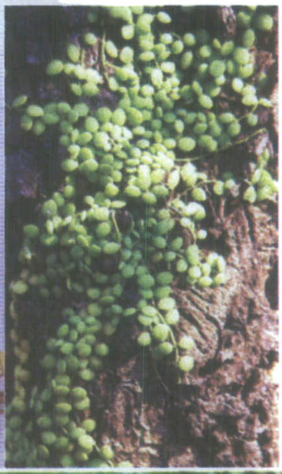
Above - BB-DF along the lower Mae Soi Valley near Chom Thong. Typical of logged over, former, teak forest.

Deciduous Dipterocarp-Oak Forest (DOF)



Left - DOF canopy, changing colour in January. Above centre - A young sapling of Dipterocarpus tuberculatus *(Dipterocarpaceae), flushing out in March; typical of dry or highly degraded sites. Above right - fallen flowers of* D. obtusifolius.

Right - Flattened acorn of Quercus kerrii *Craib (Fagaceae) a characteristic oak of DOF.*



Epiphytes of DOF: Far left - Dischidia major *(Vahl) Merr. (Asclepiadaceae) has a symbiotic relationship with ants. Ants nest in cavities formed by its bladder leaves. Adventitious roots grow into these cavities to extract moisture and nutrients from the ants' nests (centre left). Ants are also commonly found amongst the more conventional leaves of* D. nummularia *R. Br. (left).*

Ground flora species of DOF: Far left - Arundina graminifolia *(D. Don) Hochr. (Orchidaceae), September; Centre -* Platostoma coloratum *(D. Don) A.J. Platon (Labiatae), May; Above - the parasitic* Aeginetia pendunculata *Wall. (Orobanchaceae), flowering after fire in March.*

What are the characteristics of bamboo-deciduous forest (BB-DF)?

Before the latter decades of the 19th century, much of northern Thailand's lowlands were covered by vast forests, dominated by teak (*Tectona grandis* L. f. (Verbenaceae)) from valley bottoms up to 900 m elevation. However, the relentless exploitation and international trade of this highly valuable timber tree, first by foreign companies and then by Thai logging firms, changed the character of these forests. Although remnants of teak forest can still be found in a few national parks, wild teak has now become rather rare and has largely been replaced by other tree species that were formerly present in teak forest. In addition bamboos have become much more dominant. Bamboo-deciduous forest (BB-DF) is therefore a form of degraded teak forest.

To recognize former teak forest or BB-DF, look for tall trees, producing a patchy canopy, growing on fertile soils within the elevation range 300-900 m. In the dry season, canopy cover is sparse, since most trees drop their leaves. Remnant teak trees are indicative (see Box 2.2). An understorey, dominated by dense thickets of bamboos, is also characteristic. A dense shrub layer is also usually present. Woody climbers are common and epiphytic orchids and ferns grow frequently on the trunks or main branches of the larger trees. The ground layer consists mostly of deciduous herbs and grasses, the latter especially common where fires have occured. Fires are common.

In BB-DF, main canopy trees can grow up to 20-30 m tall. At least 180 tree species have been recorded in such forest, of which more than 70% are deciduous, but none approaches the former dominance of teak. Some of the more characteristic ones include valuable commercial tree species such as *Xylia xylocarpa* (Roxb.) Taub. var. *kerrii* (Craib & Hutch.) Niels. (Leguminosae, Mimosoideae), *Dalbergia cultrata* Grah *ex* Bth., *Pterocarpus macrocarpus* Kurz (both Leguminosae, Papilionoideae), *Lagerstroemia cochinchinensis* Pierre (Lythraceae), *Chukrasia tabularis* A. Juss. (Meliaceae) and *Afzelia xylocarpa* (Kurz) Craib (Leguminosae, Caesalpinioideae). Logging has favoured other less valuable species. Particularly characteristic are *Colona flagrocarpa* (Cl). Craib (Tiliaceae), *Schleichera oleosa* (Lour.) Oken (Sapindaceae), *Terminalia chebula* Retz. var. *chebula*, *T. mucronata* Craib & Hutch. (Combretaceae) and *Sterculia pexa* Pierre (Sterculiaceae). Common understorey trees include: *Vitex canescens* Kurz and *V. limoniifolia* Wall. *ex* Kurz (both Verbenaceae), *Cassia fistula* L. (Leguminosae, Caesalpinioideae), *Antidesma acidum* Retz., *Phyllanthus emblica* L. (both Euphorbiaceae), *Stereospermum neuranthum* Kurz and *Oroxylum indicum* (L.) Kurz (both Bignoniaceae).

Woody climbers (lianas), often quite large, are a notable feature of this forest type. A total of 55 species have been recorded, of which 65% are deciduous. Some of the typical species include *Millettia cinerea* Bth. and *M. extensa* (Bth.) Bth. *ex* Bak. (Leguminosae, Papilionoideae), *Combretum latifolium* Bl. (Combretaceae) and *Congea tomentosa* Roxb. var. *tomentosa* (Verbenaceae).

Thirty shrub species have been recorded in BB-DF on Doi Suthep, of which 63 % are deciduous. Some typical species include *Helicteres elongata* Wall. *ex* Boj. and *H. hirsuta* Lour. (Sterculiaceae), *Desmodium gangeticum* (L.) DC. and *D. velutinum* (Willd.) DC. ssp. *velutinum* (Leguminosae, Papilionoideae), *Sericocalyx quadrafarius* (Wall. *ex* Nees) Brem. (Acanthaceae), *Phyllanthus sootepensis* Craib and *Sauropus hirsutus* Beille (both Euphorbiaceae).

Bamboos (Gramineae, Bambusoideae), are abundant, especially in more disturbed areas. The more characteristic species include *Dendrocalamus membranaceus* Munro, *D. nudus* Pilg and *Bambusa tulda* Roxb.

At least 38 species of epiphytes have been recorded in BB-DF on Doi Suthep. They mostly belong to 3 groups: Moraceae (figs, many of which begin their lives as epiphytes), Orchidaceae, (orchids) and Pteridophytes (ferns). Particularly characteristic species include: *Ficus microcarpa* L.f. (Moraceae), an evergreen tree; *Cymbidium aloifolium* (L.) Sw. (Orchidaceae), a succulent evergreen herb and the ferns, *Platycerium wallichii* Hk. and *Drynaria bonii* C. Chr. (both deciduous Polypodiaceae). The evergreen hemiparasitic epiphyte, *Scurrula atropurpurea* (Bl.) Dans. (Loranthaceae) is restricted to bamboo-deciduous forest.

The ground is mostly bare during the dry season (November-April). The first herbs to appear are gingers (*e.g. Globba nuda* K. Lar. and *Kaempferia rotunda* L. (Zingiberaceae)), orchids

Box 2.2 - Looking at Teak

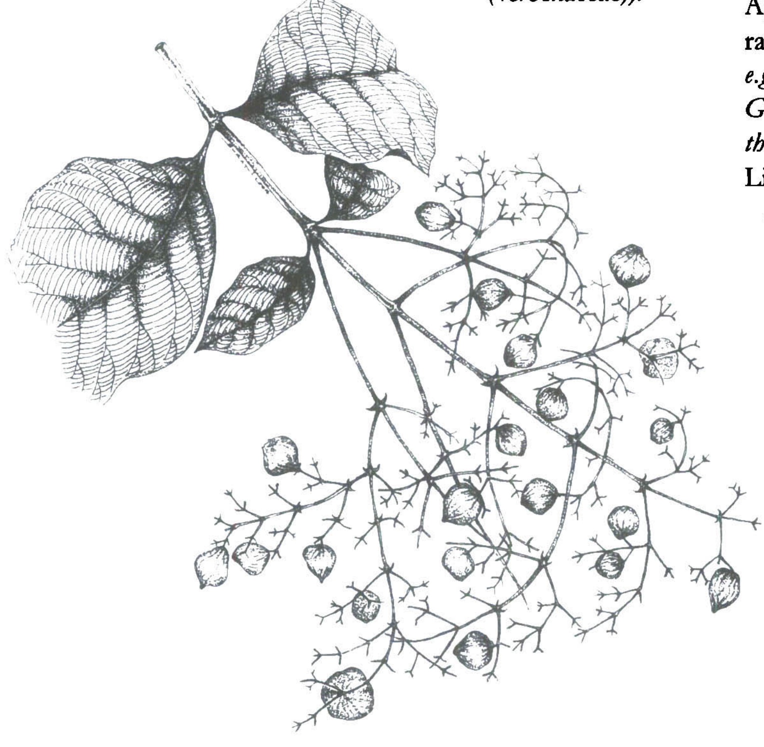
Teak is perhaps Thailand's most famous tree species. Easily recognized by its sandy brown bark, with shallow, longitudinal fissures, and a crown of large leaves, this deciduous tree once dominated much of northern Thailand's lowland forests - but not any longer.

Its downfall was its timber. Incredibly durable, easy to carve and beautiful to look at, teak wood is excellent for house beams, flooring, furniture, ornaments, boats and bridges. Beginning in the 19th century, first foreign and then Thai timber companies ruthlessly exploited northern Thailand's teak forests so that now, large, natural teak trees are a very rare sight, except in a few national parks such as Mae Wong and Mae Yom.

Teak has remarkable powers of natural regeneration and, where even just a few mature teak trees remain, teak seedlings readily establish naturally, especially on moister sites. Teak is not considered to be a framework species, since it does not attract seed-dispersing animals but, where it is absent, forest restoration plantings to rehabilitate BB-DF, would be incomplete without including it on the list of tree species planted. Teak may also be planted where it is desirable to re-establish a forest with high future economic value, but try not to create mono-species teak plantations.

Since this species is valuable, many tree nurseries grow it, but selective breeding has begun to "domesticate" the species, so make sure that any seedlings obtained from nurseries are grown from local, *wild* seed sources.

Alternatively, collect seeds from beneath local forest trees that are older than 20 years (not plantations). Air dry the fruits for 2-3 days and remove the thin, inflated calyx. Soak fruits over night; then sun-dry them by day. Repeat this cycle for 1-2 weeks. Sow seeds sparsely in germination trays in full sunlight, making sure that fully germinated seedlings do not shade germinating seeds. Germination starts after 10 days and continues for about 90 days. Total germination per cent usually exceeds 50%. Grow-on seedlings in containers in light shade. Saplings are usually ready for planting within a year after seed collection.



Teak foliage and fruits (Tectona grandis *L. f. (Verbenaceae)).*

(*e.g. Geodorum siamense* Rol. *ex* Dow., *Nervilia aragoana* Gaud. and *N. plicata* (Andr.) Schltr. (Orchidaceae)) and aroids *e.g. Amorphophallus macrorhizus* Craib (Araceae), which flower in April, before the leaves appear. After the first rains have fallen in May, more species flower *e.g. Curcuma parviflora* Wall. (Zingiberaceae), *Geodorum recurvum* (Roxb.) Alst., *Habenaria thailandica* Seid. and *Peristylus constrictus* (Lindl.) Lindl. (all Orchidaceae) and the vine *Stemona burkillii* Prain (Stemonaceae). By mid-July, many other herbs have matured, including many fern allies, *e.g. Selaginella ostenfeldii* Hier. (Selaginellaceae) and ferns such as *Anisco-campium cumingianum* Presl, *Kuniwatsukia cuspidata* (Bedd.) Pichi-Ser. (both Athyriaceae) and *Dryopteris cochleata* (D. Don) C. Chr. (Dryopteridaceae), with its bi-morphic fronds. By August, the ground is covered with a dense and diverse herbaceous vegetation, which dies back and subsequently burns with the onset of the dry season.

What are the special challenges when restoring BB-DF?

The greatest problem with restoring BB-DF are the bamboos. Bamboos are giant grasses and like other grasses, they are highly aggressive competitors. Their dense root systems fully exploit the soil; they cast dense shade and, in the dry season, they smother nearby tree seedlings with a dense layer of leaf litter. Consequently, any trees planted near large bamboo clumps cannot compete and gradually fade away. Therefore, controlling (but not eliminating) the spread of bamboos is essential for successful tree establishment in BB-DF (see Box 2.3). Luckily bamboo canes and bamboo shoots are useful products, so local people usually need no encouragement to harvest them, to give planted trees a higher chance of survival.

Smaller grasses characteristic of BB-DF include *Oryza meyeriana* (Zoll. & Mor.) Baill. var. *granulata* (Watt) Duist. (Gramineae), *Microstegium vagans* (Nees *ex* Steud.) A. Camus and *Panicum notatum* Retz.(both Gramineae). Together with the bamboos, they constitute a serious fire hazard. Consequently, weeding, firebreak construction and an effective fire prevention program are all particularly important when restoring this forest type.

Box 2.3 - Looking at Bamboos

Bamboos are giant 'woody' grasses in the family Gramineae, sub-family Bambusoideae. More than 1,400 species grow mostly in the tropics and sub-tropics, with more than 25 species found in northern Thailand. Some giants grow up to 15 m tall and reach 30 cm in diameter. They are the world's fastest-growing woody plants and are among the most useful.

A bamboo plant consists of a system of underground rhizomes (stems), from which aerial shoots (culms) grow. The culms have annular nodes and hollow internodes. Branching occurs at the nodes, and leaves grow from the branches. The hollow, rigid woody structure of larger bamboos makes them very strong, whilst thinner canes have great flexibility: properties that make bamboo a versatile construction and craft material. The canes are used for all kinds of temporary construction and furniture and are split and woven to make mats and baskets. Young culm buds ("bamboo shoots") are a popular vegetable in oriental cuisine.

Some bamboo species are renowned for their gregarious flowering habits *i.e.* after perhaps decades of vegetative growth, all individuals of a species flower and then their culms die back simultaneously over their entire ranges, producing masses of seeds. Seed predators are unable to eat all the seeds so some survive to grow into the next generation of bamboo plants.

Bamboos are classified into two types: monopodial (or clumping); and sympodial (or scrambling).

Clumping bamboos produce a series of culms close together, in a single clump. These plants tend to produce stronger culms than scrambling bamboos and are, therefore, more widely used for light construction.

In contrast, scrambling bamboos produce very long, rhizomes, which can spread considerable distances underground. Each node of the rhizomes can produce a new shoot, from which a new rhizome system can develop. Whilst this characteristic is sometimes beneficial *e.g.* for controlling soil erosion, it also enables these plants to become highly invasive and to suppress tree establishment and growth.

If forest restoration is threatened by invasive bamboos, the bamboos must be controlled. Cutting back the shoots may be effective, but if it is not followed up rigorously, it actually stimlates spread of the rhizomes. Therefore, a systemic herbicide such as glyphosate (Round-up) can be applied to the cut culm stumps to kill the rhizomes. Bamboos are characteristic of BB-DF, so be careful not to completely eliminate them.

What are the distinguishing features of deciduous dipterocarp-oak forest (DOF)?

Typically, DOF grows in the driest or most degraded areas, from valley bottoms up to 800-900 m, often along ridges with little or no top soil, alternating with BB-DF in moister gullies. It is a secondary forest, in which frequent fires, eroded soils and other disturbing factors prevent the forest from developing into BB-DF and ultimately into teak forest.

To recognize this forest type, look for short trees (rarely exceeding 20 m) forming an open or irregular canopy. A ground layer, dominated by grasses and sedges, is characteristic. Woody climbers are rare and the shrub layer consists mainly of the saplings of the common tree species. Large bamboos are absent.

In DOF, more than 80% of tree species are completely deciduous, shedding their leaves in the dry season and flushing green again, usually before the onset of the rainy season. With around 100 tree species, of which 24 are common or abundant, DOF has a relatively low tree species richness, compared with the other forest types.

With their huge leaves and massive fruits with wings derived from the calyx, the *Dipterocarpus* species are undoubtedly the most easily recognised and characteristic tree species in this forest type. In many of the most degraded areas, especially along ridge crests, *Dipterocarpus tuberculatus* Roxb. var. *tuberculatus* (Dipterocarpaceae) approaches dominance, but on gentle slopes or in slightly moister areas, this species tends to be replaced by *D. obtusifolius* Teijsm. *ex* Miq. var. *obtusifolius.* Other dominating tree species of the Dipterocarpaceae family include *Shorea obtusa* Wall. *ex* Bl. and *S. siamensis* Miq. var. *siamensis.*

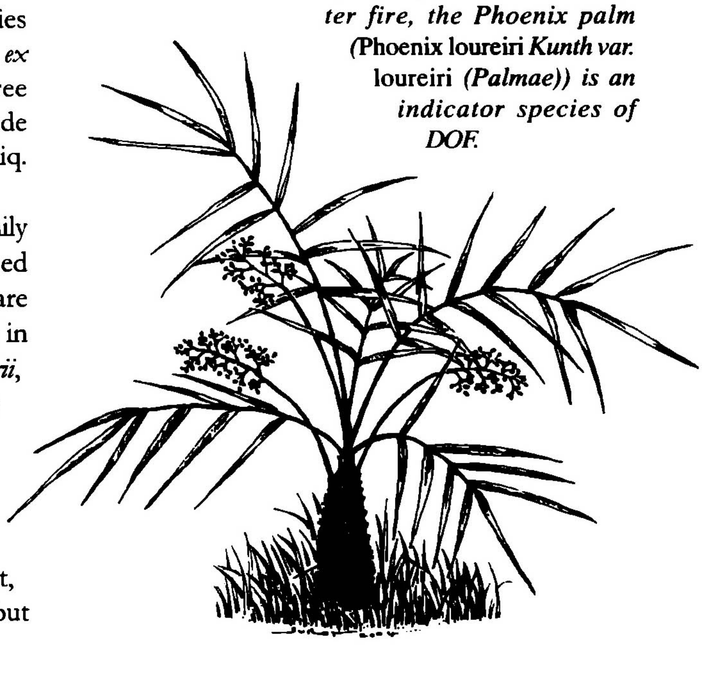
Oaks and chestnuts, members of the family Fagaceae, are the next most easily recognised group of tree species, especially when they are in fruit, although many of them also occur in other forest types. *Quercus kerrii* Craib var. *kerrii*, *Q. aliena* Bl., *Q. brandisiana* Kurz, *Lithocarpus elegans* (Bl.) Hatus. *ex* Soep., *Castanopsis diversifolia* King *ex* Hk. f. and *C. argyrophylla* King *ex* Hk. f. (the last is one of the very few evergreen tree species in DOF) are especially common. Where fires are frequent, oaks and chestnuts may be rare or absent, but if such areas are protected from fire for 30 years or more, they slowly re-establish themselves, provided mature, seed-producing trees survive nearby (Kafle, 1997 and Meng, 1997).

The small palm, *Phoenix loureiri* Kunth var. *loureiri* (Palmae), so-called because it sprouts new leaves after fire from a woody stem, is an easily recognized indicator species of this forest type. Other common characteristic tree species include *Gluta usitata* (Wall.) Hou and *Buchanania lanzan* Spreng. (both Anacardiaceae), *Craibiodendron stellatum* (Pierre) W.W. Sm. (Ericaceae), *Strychnos nuxvomica* L. (Loganiaceae), *Tristaniopsis burmanica* (Griff.) Wils. & Wat. (Myrtaceae) and *Anneslea fragrans* Wall. (Theaceae).

DOF supports only 14 species of woody climbers, of which the deciduous species *Spatholobus parviflorus* (Roxb.) O.K. (Leguminosae, Papilionoideae), *Aganosma marginata* (Roxb.) G. Don (Apocynaceae) and *Celastrus paniculatus* Willd. (Celastraceae) are the most common.

Shrubs (29 species) and treelets (48 species) are abundant. Some common examples are: *Helicteres isora* L. (Sterculiaceae), *Grewia abutilifolia* Vent. *ex* Juss. (Tiliaceae); *Desmodium motorium* (Houtt.) Merr. and *Indigofera cassioides* Rottl. *ex* DC. (both Leguminosae, Papilionoideae); *Gardenia obtusifolia* Roxb. *ex* Kurz and *Pavetta fruticosa* L. (both Rubiaceae), *Strobilanthes apricus* (Hance) T. And. (Acanthaceae), *Premna herbacea* Roxb. (Verbenaceae) and *Breynia fruticosa* (L.) Hk. f., (Euphorbiaceae).

*Re-sprouting from the ashes after fire, the Phoenix palm (*Phoenix loureiri *Kunth var.* loureiri *(Palmae)) is an indicator species of DOF.*



Common vines in burnt areas include *Dunbaria bella* Prain (Leguminosae, Papilionoideae), *Solena heterophylla* Lour. ssp. *heterophylla* (Cucurbitaceae) and *Streptocaulon juventas* (Lour.) Merr. (Asclepiadaceae).

Of the 47 epiphytes, recorded in DOF on Doi Suthep, perhaps the most characteristic is *Dischidia major* (Vahl) Merr. (Asclepiadaceae), due to its extraordinary morphology and its association with ants. This plant grows bladder-like leaves, within which ants nest. Organic debris, brought in by the ants, supplies the plant with soil, moisture and nutrients. Several epiphytic orchid species also grow naturally in DOF, but some have disappeared due to over-collection for their ornamental value. Typical epiphytic orchids include: *Cleisomeria lanata* (Lindl.) Lindl., *Cleisostoma arietinum* (Rchb. f.) Garay, *Cymbidium ensifolium* (L.) Sw., *Dendrobium lindleyi* Steud., *D. porphyrophyllum* Guill., *D. secundum* (Bl.) Lindl., *Eria acervata* Lindl., *E. pannea* Lindl., *Rhynchogyna saccata* Seid. & Garay and *Vanda brunnea* Rchb. f. Two epiphytic ferns are also common in DOF: *Drynaria rigidula* (Sw.) Bedd. and *Platycerium wallichii* Hk. (Polypodiaceae).

The ground layer is dominated by grasses (Gramineae) and sedges (Cyperaceae), which dry out in the hot season, providing fuel for fires. Some of the common grasses include *Apluda mutica* L., *Arundinella setosa* Trin., *Eulalia siamensis* Bor, *Heteropogon contortus* (L.) P. Beauv. *ex* Roem. & Schult. and *Schizachyrium sanguineum* (Retz.) Alst. Sedges include *Carex continua* Cl., *Cyperus cuspidatus* Kunth, *Rhynchospora rubra* (Lour.) Mak. and *Scleria levis* Retz. Growing among the grasses, several ginger species (Zingiberaceae) are common *e.g.* *Curcuma zedoaria* (Berg.) Rosc., *Globba nuda* K. Lar. and *Kaempferia rotunda* L. Other common ground herbs include *Barleria cristata* L. (Acanthaceae), *Platostoma coloratum* (D. Don) A.J. Platon (Labiatae), *Striga masuria* (B.-H. *ex* Bth.) Bth. (Scrophulariaceae) and *Aeginetia indica* Roxb. (Orobanchaceae); the latter two are parasitic on plant roots. The fern ally, *Selaginella ostenfeldii* Hiern. (Selaginellaceae) and the ferns *Adiantum philippense* L., *A. zollingeri* Mett. *ex* Kuhn and *Cheilanthes tenuifolia* (Burm. f.) Sw. (all Parkeriaceae) are characteristic of the ground flora of DOF.

In burnt areas, at the upper elevational limits of DOF, pines (see Box 2.1) sometimes grow amongst the dipterocarps and oaks. This, rather rare, forest type is termed DOF+PINE.

What are the special challenges when restoring DOF?

Most DOF sites were originally disturbed by logging and have been subsequently degraded by decades of chopping for fire-wood, cattle browsing and frequent burning. The DOF sites that are currently available for restoration, are mostly those with soils too poor to have been completely cleared of trees and cultivated. They often retain some stunted trees or coppicing tree stumps of a few highly resilient (usually wind-dispersed) species. This means that the number of trees planted can be correspondingly reduced (often to as low as 200-300 per rai = 1,250-1,875 per hectare) to compensate for the density of trees or stumps remaining. Restoration usually focusses on enrichment planting, to i) increase the diversity of tree species present; ii) re-introduce fleshy-fruited tree species, attractive to wildlife and iii) improve soil conditions (*e.g.* by planting legumes).

In the lowlands, human population density is highest, so conflicts between forest restoration aims and human needs are intense. A high level of commitment from local communities is vital to cease disturbances that will endanger the planted trees. Education and public relations are, therefore, critical for successful restoration.

Dried grasses and leaf litter provide ideal fuel for fire. Therefore, fire prevention measures are particularly important at DOF sites. Soil conditions are very poor, with highly eroded, lateritic soils, with impeded drainage and low nutrient levels. Digging holes for tree planting in such soils is very hard work, so the labour costs for tree planting can be high. In the dry season, the upper soil layers quickly dry out, whilst in the rainy season, the soil becomes waterlogged due to poor drainage. This suffocates tree roots, killing the planted trees. Applying mulch and using polymer gels, when planting trees, can help reduce immediate post-planting mortality. Watering the trees immediately after planting can also help increase the survival of planted trees. Hire a water tanker if the site is accessible by road. Frequent fertilizer application is mandatory and soil amelioration measures before planting, *e.g.* green manure, should be considered. Weeds grow relatively slowly on DOF sites, so weeding may be needed less frequently than at EGF sites.

Box 2.4 - Looking at Dipterocarps

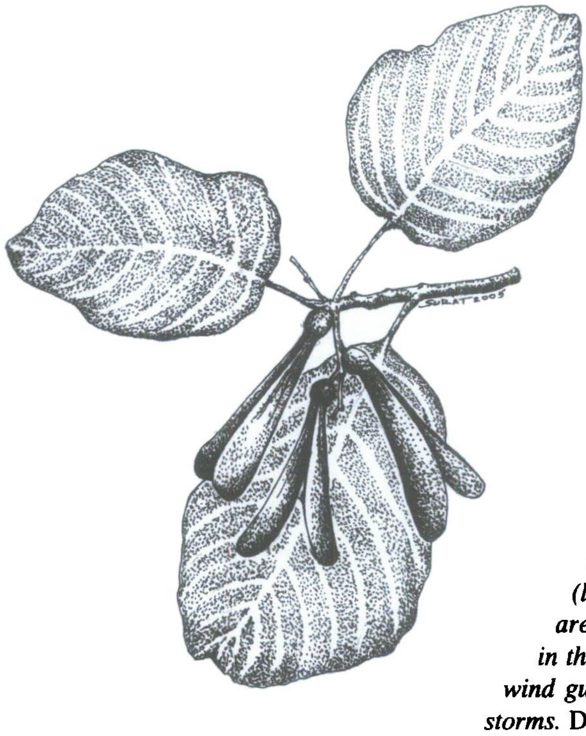
The tree family, Dipterocarpaceae, comprises nearly 600 species in 16 genera. Most species are native to South or South-East Asia. Less than 50 grow in tropical Africa and America. Within their South-East Asian stronghold, Dipterocarps dominate several forest types and are known for their diversity and abundance. The taller species feature prominently in international tropical timber markets, as well as meeting domestic timber demands.

Resins, oils and tannins are also valuable products obtained from Dipterocarps. Resin is extracted by hollowing out a bowl-shaped depression in the tree trunk and then scorching the wood above it to stimulate resin secretion. Solidified resins are called "*dammar*", whilst thin oils are called "*gurjun*". Liquid resin, which contains essential oils (oleoresins), is used as an ingredient in traditional medicinal remedies, as a liquid fuel and in the perfume industry. *Gurjun* is used as a substitute for linseed oil in paints and for making varnish. *Gurjun*, from *Dipterocarpus turbinatus*, is also used to make torches, ink and is mixed with *dammar* to caulk boats and to waterproof bamboo. Tannins, from the leaves and bark of *Dipterocarpus tuberculatus* are used to tan leather.

Even in the most severely degraded DOF, dipterocarps are usually strongly represented by re-sprouting tree stumps and remnant trees. Also, since their seeds are wind dispersed, there is usually no need to replant them. Most dipterocarps do not meet the criteria of framework species (Part 5). They grow slowly and they are unattractive to seed-dispersing wildlife, but they are a major component of both DOF and MXF. So, where they have become extirpated, planting them, along with framework species, can acclerate recovery of the original species composition of the climax forest type.

Dipterocarps are difficult to propagate from seed, because they flower unpredictably and their seeds are recalcitrant. Researchers have not yet developed a reliable technique to store viable seeds for longer than a few weeks. Harvesting wildlings is, therefore, often the most practicable way to grow saplings for planting (see Box 6.1). Vegetative propagation is an alternative, but it is relatively expensive and carries the risk of reducing genetic variability within species. Researchers have developed simple cutting techniques for several species, so seek professional advice to find the best method for the particular species you want to grow.

Tapping resin from this relatively young Dipterocarpus costatus *tree in MXF has almost killed it.*



Two dominant Dipterocarpus *species, characteristic of DOF in northern Thailand are notable for their large, broad, thick leaves and large nuts, which remain attached to wings derived from the calyx.* D. tuberculatus *(left) has the largest leaves and fruits. Although the nuts are winged, they are very heavy and do not fly very far except in the strongest gales. They are produced in April-May when wind gust speeds reach maximum velocity during pre-monsoon storms.* D. obtusifolius *has slightly smaller leaves and fruits.*

SECTION 4 - FOREST TYPE AND RESTORATION STRATEGY

How can the original forest type be determined?

Understanding which forest type you are dealing with will help you to decide which tree species to plant and which management strategy to apply after planting them. However, in areas, which have remained deforested for several decades, determining what the original forest type was can be difficult, especially where few original trees survive in the landscape. Under such circumstances, local knowledge becomes invaluable.

Ask elderly local people if they can remember which tree species originally grew on the site to be restored. Ask them to guide you around the sites and look for remnant trees or sprouting tree stumps, which may have survived since deforestation occurred. Collect specimens of leaves and flowers (if available) from the trees and get them identified by a botanist. On a map, identify the nearest area of forest, at the same elevation as the site to be restored. Survey the trees there, collect plant specimens and get them identified.

Once you are sure you have the correct scientific names of the trees you have observed, look them up in botanical text books (your national or local flora or internet resources) to discover which kind of forest type they usually grow in. Probably the best source for matching tree species with their preferred forest types in northern Thailand is Maxwell's published database of plant species and forest habitats of Doi Suthep-Pui National Park. This presents detailed descriptions of forest types that are typical of the northern mountains (up to 1,685 m elevation) and comprehensive species lists for each of them (Maxwell and Elliott, 2001). Similar publications are urgently needed for other regions.

Once a list of indigenous tree species has been compiled for the forest type to be restored, find out if any of them have been identified as framework species (see Part 9). Otherwise follow the steps in Part 5 to identify candidate species for testing as framework species. Find living examples in nearby forest and begin phenology studies and seed collection (Part 6). Grow them in a nursery and test them in field trials (Part 7).

Each forest type has particular conditions, which necessitate adjustments to management activities *e.g.* numbers and species of trees planted, planting methods, frequency of weeding and fertilzer application *etc.* These have been outlined in Sections 3 & 4. Once you have identified the forest type you are restoring, read Part 7 and modify the planting and maintenance strategy according to the forest type.

Are some forest types a higher priority for restoration than others?

Since forest restoration is primarily a tool to conserve biodiversity, forest types with high biodiversity and those which support rare or endangered species should receive the highest priority for restoration. The analysis presented in Box 2.5, shows that evergreen forest has the highest conservation value, both in terms of species richness, rare species and habitat-restricted species and should receive the highest priority for forest restoration. In addition, evergreen forest is a relatively rare forest type, since there is less land at higher elevations than at lower elevations. So, for maximum positive impact on biodiversity, restoration of evergreen forests should be a high priority.

However, other forest types should not be ignored. MXF is also a rare habitat, since it grows in a narrow elevation range and favours moist areas, often near running water. It also supports high biodiversity. Its tendency to grow in narrow corridors, along water courses, makes it particularly vulnerable to infrastructure development at mid-elevations. Dams, housing estates, resorts and golf courses all require water, and roads tend to follow valley bottoms, so MXF is often the first forest type to disappear from a landscape.

Although DOF supports lower biodiversity than the other forest types, it has a high degree of "uniqueness", with 28% of its plant species not able to grow in other forest types. Growing in the lowlands, where most people also live, this forest type is particularly threatened by cattle browsing, fire, charcoal making and firewood collection. So even this relatively species-poor forest type is worth restoring, if it is disappearing from the landscape.

Box 2.5 - Forest Types and Biodiversity

Doi Suthep-Pui in northern Thailand, was designated a national park in 1981, covering 261 sq km. Information about each of the >2,220 vascular plants found in the park (*e.g.* habit, habitat, elevation range *etc.*) were entered into a computer database. Analysis of this database allowed the conservation value of each of the forest types describe in this Part to be determined (Maxwell and Elliott, 2001).

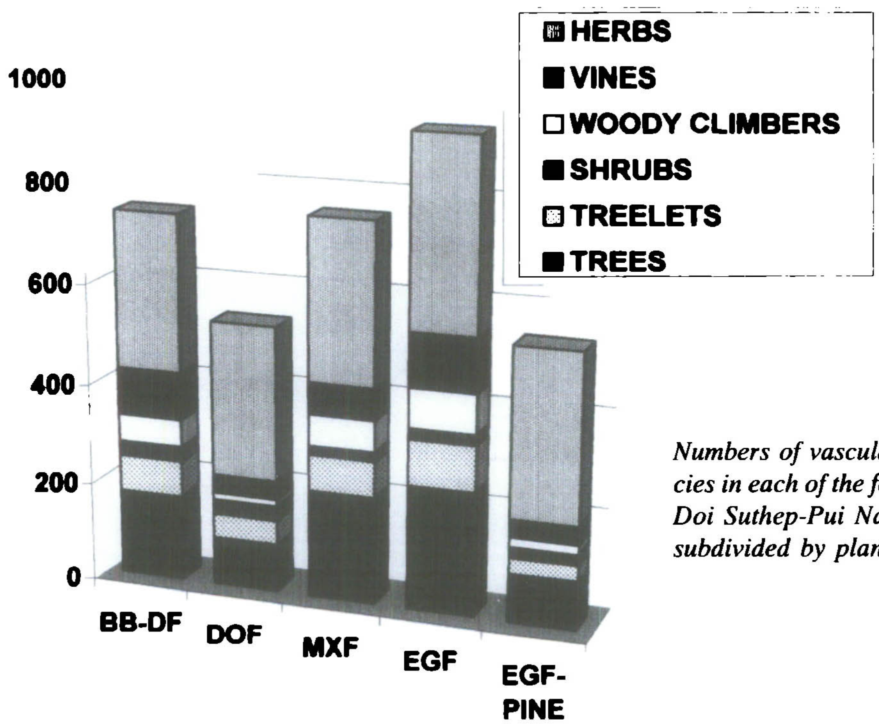
With 930 species, EGF has the highest species richness of vascular plants, compared with all other forest types. BB-DF and MXF are also highly diverse, with similar numbers of plant species (740 and 755, respectively). Habitats that are characteristic of disturbed or degraded areas generally support the fewest plant species, with DOF and EGF-PINE having "only" 533 and 540 species, respectively.

EGF also supports the highest number of vascular plant species that are "habitat-restricted". Therefore, further losses of evergreen forest would result in the extirpation of many plant species, which do not grow in any of the other forest types. In contrast, MXF supports the fewest habitat-restricted species, compared with the other forest types. The data also indicate that DOF is one of the most distinctive forest types, with 28 % of its plant species occurring in none of the other forest types.

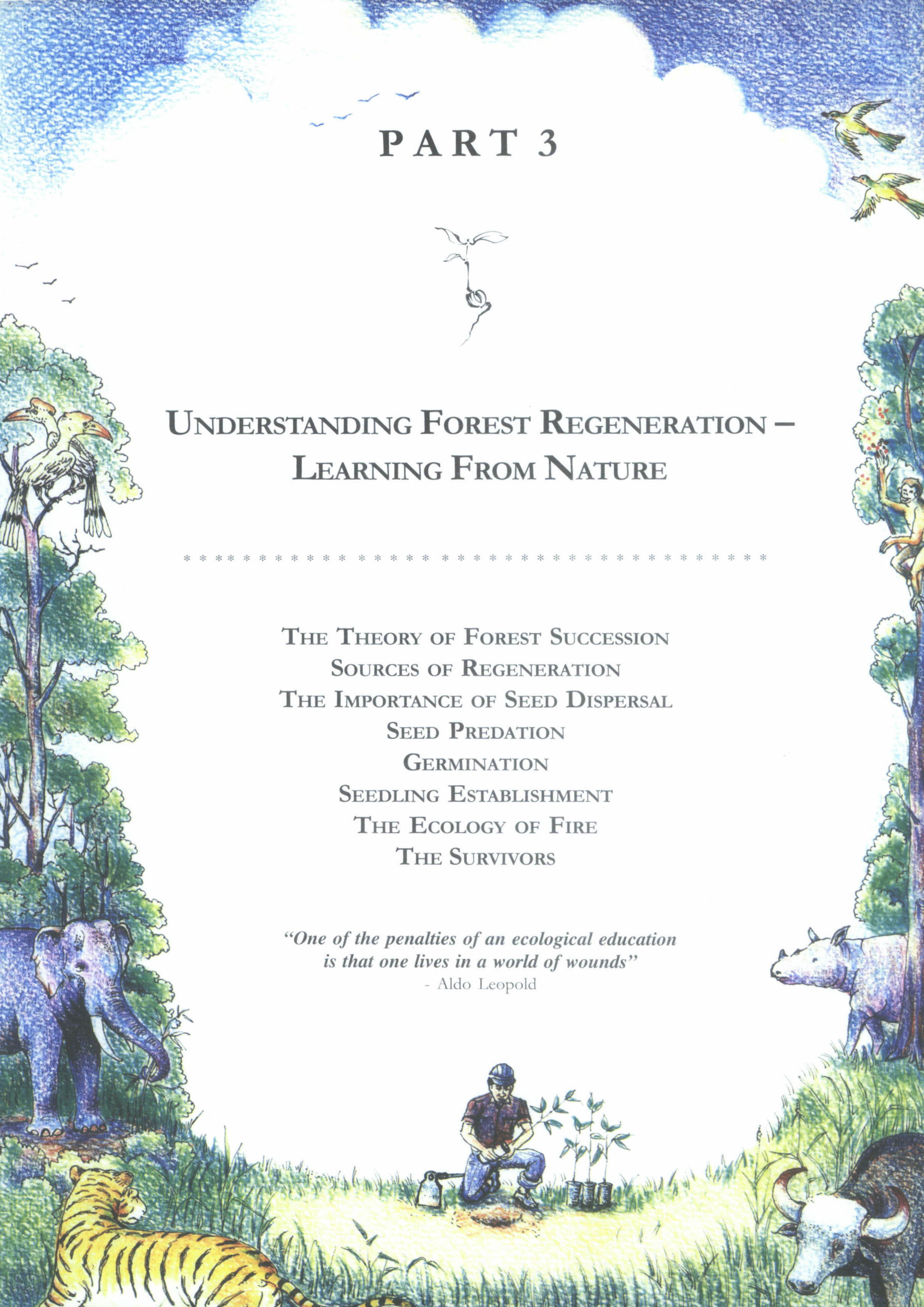
EGF also supports far more rare or endangered plant species than any of the other forest types. Restoring EGF would therefore expand the habitat for large numbers of rare or endangered species and could help to save many of them from extinction.

Numbers of habitat-restricted vascular plant species and rare or endangered species in each forest type.

Forest Type	Number of species restricted to each forest type (% of habitat species richness)	Number of rare or endangered species (% of habitat species richness)
EGF	230 (25%)	314 (34%)
EGF-PINE	120 (22%)	141 (26%)
MXF	58 (8%)	147 (19%)
BB-DF	141 (19%)	153 (21%)
DOF	150 (28%)	121 (23%)



Numbers of vascular plant species in each of the forest types of Doi Suthep-Pui National Park, subdivided by plant habit.



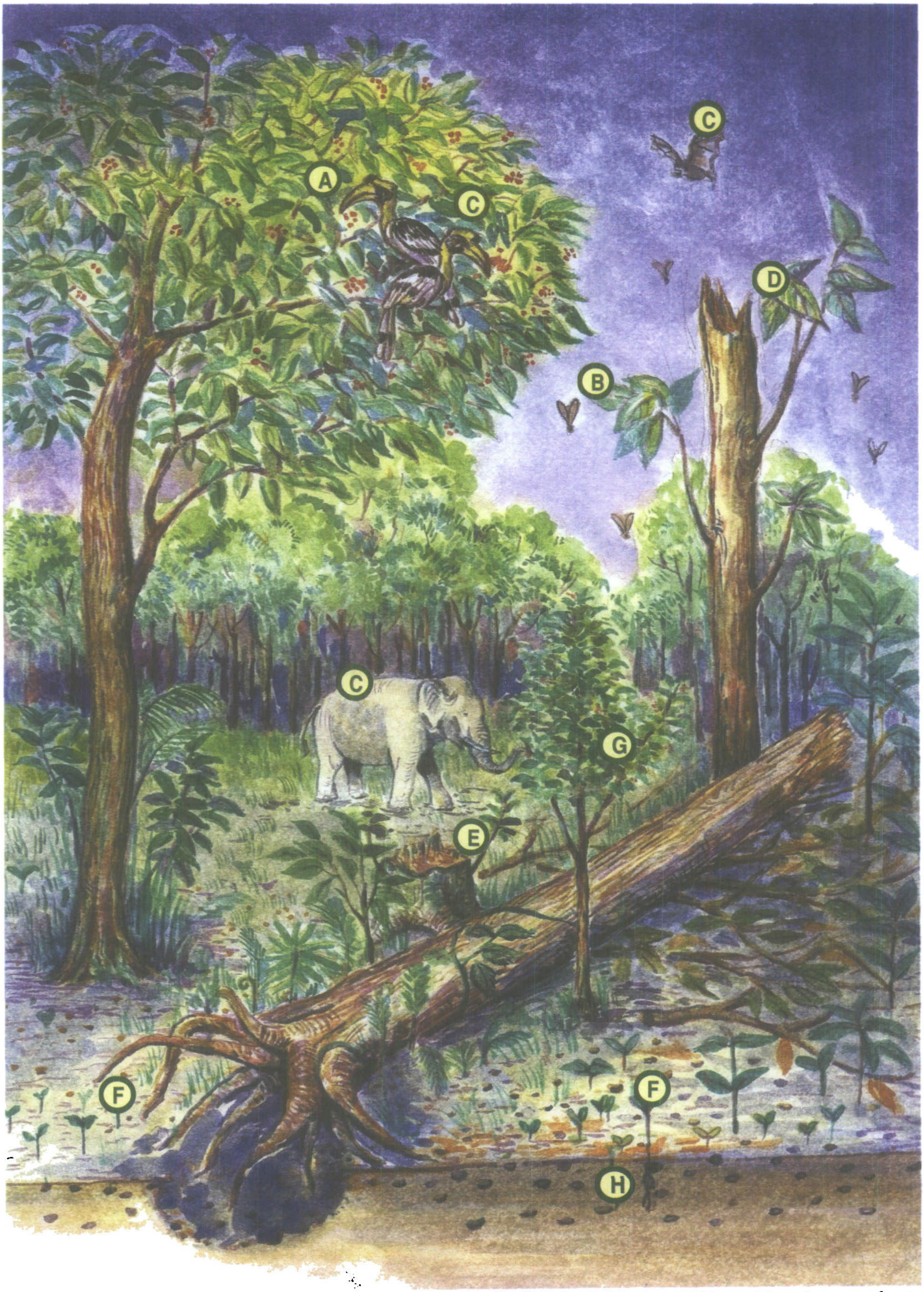
PART 3

UNDERSTANDING FOREST REGENERATION – LEARNING FROM NATURE

THE THEORY OF FOREST SUCCESSION
SOURCES OF REGENERATION
THE IMPORTANCE OF SEED DISPERSAL
SEED PREDATION
GERMINATION
SEEDLING ESTABLISHMENT
THE ECOLOGY OF FIRE
THE SURVIVORS

"One of the penalties of an ecological education is that one lives in a world of wounds"
- Aldo Leopold

Mechanisms of Forest Regeneration



In tree-fall gaps within intact forest, succession proceeds rapidly. Nearby fruiting trees (A) provide a dense seed rain (B). Surrounding forest provides habitat for seed-dispersing animals (C). Damaged trees (D) and tree stumps (E) regrow. Seedlings (F) and saplings (G), formerly suppressed by the dense forest canopy now grow rapidly. Seeds in the soil seed bank germinate (H). In large deforested areas, created by humans, most of these natural mechanisms of forest regeneration are disabled.

UNDERSTANDING FOREST REGENERATION – LEARNING FROM NATURE

Some people take the view that deforested areas should be left to recover naturally and that forest restoration is unnecessary interference with nature. This view fails to recognize that the situation in most large deforested areas is far from "natural".

Humans have not merely destroyed forest; we have also destroyed the natural mechanisms of forest regeneration.

The elimination of most large seed-dispersing animals by hunting now makes it almost impossible for climax forest to re-establish itself by natural means. Nearly all wildfires, which burn any tree seedlings that may become established, are also started by humans. Unless a concerted effort is made to restore the former mechanisms of forest regeneration, most deforested areas in the tropics will remain dominated by herbaceous weeds and maintained by frequent fires. Forest restoration is merely an attempt to correct the "unnatural" creation of so many large deforested areas by Humankind. Its success depends on a thorough understanding of the natural mechanisms of forest regeneration and consequently, development of methods to re-instate them (see Parts 4 & 5). Therefore, in this part, we present an overview of natural regeneration of seasonally dry tropical forest ecosystems, based mostly on FORRU's research on the forests of Doi Suthep-Pui National Park in northern Thailand.

SECTION 1 - THE THEORY OF FOREST SUCCESSION

Ecologists regard forest regeneration as one particular example of "succession" – a series of predictable changes in ecosystem structure and composition over time, which if allowed to run its course, eventually results in a final, stable ecosystem, called the "climax" ecosystem. The climax ecosystem, for any particular area, depends on soil type and climatic conditions.

In Southeast Asia, wherever annual rainfall exceeds 1,000 mm, the climax ecosystem is some type of primary forest. Disturbance of primary forest, by tree cutting, fire and so on, causes it to revert to an earlier, temporary ecosystem in the successional series known as a "seral stage". Once disturbance ceases, sequential changes in species composition occur due to interactions among plants and animals with their surrounding environment. Shrubs shade out grasses; trees shade out shrubs and light-demanding, pioneer tree species are eventually shaded out by shade-tolerant climax ones.

Thus, degraded grassland reverts back into forest, which becomes progressively denser, more structurally complex and more species-rich, as the processes of succession propel it towards the climax condition.

What are the differences between pioneer and climax tree species?

Tree species may be divided into two categories, depending on when they appear in the sequence of forest succession. Pioneer tree species are those that first colonize deforested sites. Over many years, as succession proceeds, they are gradually replaced by tree species characteristic of mature forest; the so-called climax tree species.

The main distinctions between pioneer and climax trees are that the seeds of pioneers can germinate only in full sunlight and their seedlings cannot grow in the shade that is cast by a forest canopy, whereas climax tree seeds can germinate in shade and their seedlings are shade tolerant.

Pioneer trees grow rapidly and usually produce large numbers of small fruits and seeds dispersed by the wind or small birds, at a young age. Pioneer tree seeds are easily dispersed over long distances and can lie dormant in the soil, before germinating when a gap is formed and light intensity increases. However, once the forest canopy closes, no more seedlings of pioneer species can grow to maturity.

Climax tree species grow for many years, consolidating their position in the forest ecosystem, before flowering and fruiting. They tend to produce large, animal-dispersed, non-dormant seeds, containing large food reserves, which sustain seedlings, whilst they grow slowly in shaded conditions. Therefore, climax tree species can regenerate beneath their own shade. This gives rise to the relatively stable species composition of climax forest.

In reality, these distinctions between pioneer and climax tree species are not so sharply defined. Some tree species may combine both pioneer and climax traits. For example, *Schima wallichii* (Theaceae) is an evergreen tree with small wind-dispersed seeds. This species readily colonises abandoned agricultural fields at elevations of 950-1,400 m, yet it is commonly found growing to a very large size in undisturbed evergreen forest. Furthermore, many climax tree species can perform as well as pioneers when planted out in deforested sites. Such tree species are not limited by the dry, hot, sunny conditions of deforested sites, but by lack of seed dispersal, since they tend to have large, animal-dispersed seeds.

This means that tree planting programs need not be restricted to pioneer species. Carefully selected, climax tree species can be planted simultaneously with pioneers to short-circuit succession and recreate a primary forest faster than would happen naturally. So, succession can be manipulated both forwards and backwards. Tree cutting reverses it, whilst forest restoration activities accelerate it forwards.

So why don't forests grow back naturally?

If nature has such remarkable powers of self-regeneration, why is forest restoration necessary? When a dead tree falls to the ground in a forest, a hole is created in the forest canopy. For the first time in decades, the forest floor is bathed in sunlight, which stimulates an intense struggle amongst a surplus of existing tree seedlings and saplings to grow and fill the gap. Only the fastest-growing tree will win. All the others will fade away in the victor's shade. Within a few years, the tree that died will be consumed by termites and fungi, releasing its nutrients into the soil. In its place, another tree will stand, perhaps for a hundred years or more until one day, a violent storm may send it crashing to the ground, to be recycled like its predecessor.

Within small gaps in tropical forest, natural processes of self-regeneration work efficiently to bring about swift forest recovery. In contrast, in large deforested areas, forest regeneration is either very slow or fails to occur at all.

Large deforested areas can be caused by natural catastrophes, such as volcanic eruptions or cyclones, but such occurrences are rare. Today, wide-spread deforestation is mostly the result of human activities such as logging, slash-and-burn agriculture and infrastructure development. Where disturbances are frequent, natural succession is impeded, resulting in a persistent pre-climax ecosystem (termed "plagio-climax"). Under such circumstances, natural mechanisms of succession are insufficient to restore the original forest ecosystem. The cycle of degradation must be broken by counteracting the factors that prevent tree establishment and, where a seed supply is limiting, by tree planting.

What factors limit forest regeneration in large deforested areas?

In the large, open, deforested areas, that remain after logging or cultivation, the establishment of forest trees depends on seeds being dispersed into the areas. The seeds must land where conditions are suitable for their germination and they must escape the attention of seed-eating animals - the so called "seed predators". After germination, tree seedlings must win an intense competition with weeds for light, moisture and nutrients. The growing trees must avoid being burnt by wildfires or eaten by cattle. The factors that limit forest regeneration are therefore:-

- Lack of a seed source
- Lack of seed dispersers
- Seed predation
- Unsuitable soil and microclimatic conditions for germination and early seedling growth
- Dominance by herbaceous weeds
- Fire
- Browsing by domestic animals

SECTION 2 – SOURCES OF REGENERATION

All trees start life as seeds, so forest succession ultimately depends on the presence of fruiting trees nearby. In a largely deforested landscape, some tree species may be represented by a few scattered, isolated, individuals that somehow escaped the axe or chain saw, or there may be remnant forest patches producing seeds of a wider range of tree species. Distances from seed sources have a critical effect on the rate of forest regeneration and on the diversity of the tree species that grow back in any particular location. Fruiting trees not only provide seeds for forest regeneration, they also attract frugivorous, seed-dispersing animals. Therefore, protection of any fruiting trees in a deforested landscape will greatly enhance natural forest regeneration.

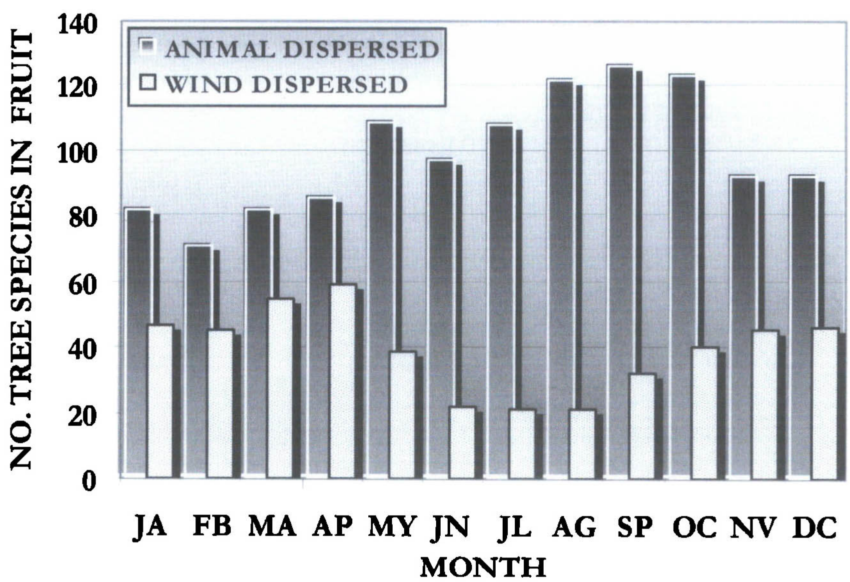
When do forest trees produce seed?

In a tropical forest, fruiting is highly variable among species, among sites and from year to year. Most tree species fruit once per year, but some fruit twice per year and a few, such as the talipot palm (*Corypha umbraculifera*) have one big fruiting event just before dying (a fruiting pattern termed "monocarpy"). Another fruiting pattern, common amongst tree species of the Fagaceae (oaks and chestnuts) and Dipterocarpaceae is known as "masting", when an entire species population fruits heavily and synchronously at intervals of several years.

Different tree species flower and fruit at different times of the year, but at the community level, seasonal cycles in fruiting and seed dispersal are evident, particularly in seasonally dry tropical forests. The study of these seasonal cycles is called forest phenology.

In Doi Suthep-Pui National Park, tree species with wind-dispersed seeds tend to develop their fruits and seeds during the dry season. Very few wind-dispersed tree species fruit in the rainy season. Tree seed dispersal by wind peaks at the end of the dry season in April, when 43% of wind-dispersed tree species release their seeds. Not surprisingly, this is also when the strongest winds occur during pre-monsoon storms (Elliott *et al.*, 1994). In contrast, the number of animal-dispersed tree species in fruit is fairly high all year round, but gradually increases during the rainy season, peaking towards the end of the rainy season in September (when 37% of animal-dispersed tree species bear fruit) (see Fig 3.1).

Figure 3.1 - Seasonal cycles of fruiting in animal-dispersed (283 species) and wind-dispersed (136 species) tree species, Doi Suthep-Pui National Park, northern Thailand (source: CMU Herbarium Database , J. F. Maxwell)



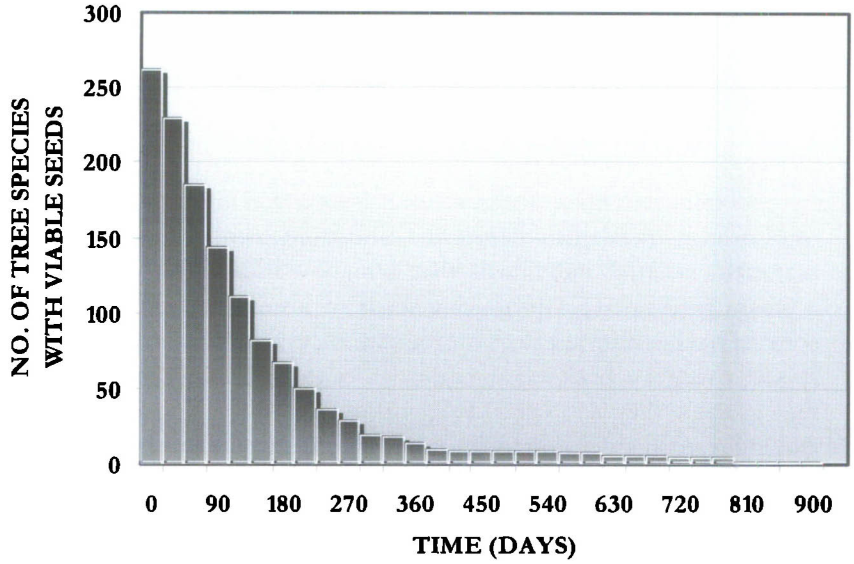


Figure 3.2 - After deforestation, the number of original forest tree species represented by viable seeds in the soil seed bank declines exponentially over time (data from FORRU's nursery experiments).

What is the soil seed bank?

The soil seed bank is the number of viable seeds present in a known volume of soil. It is usually measured by taking core-samples of soil (often sub-divided by depth), spreading the soil in germination trays, watering it and then counting the numbers of seeds that subsequently germinate. It is usually expressed as numbers of seeds per cubic metre of soil. For studies of forest regeneration, the soil seed bank can be divided into those seeds remaining from the original forest and those that have been dispersed into the area since deforestation occurred.

Where deforestation has been followed by prolonged or repeated disturbances, it is unlikely that seeds from the original forest play a major role in forest regeneration. Although a few tree species produce seeds that can survive dormant in the soil for 2-3 years, seeds of the vast majority of tropical tree species loose their viability within a few weeks or a few months after dispersal has occured.

Of 262 tree seed species from northern Thailand, which were tested in FORRU's research nursery, only 5.3 percent produced seeds with a maximum dormancy of longer than a year (see Fig. 3.2, above).

Therefore, in most deforested sites older than a few years, the soil seed bank is comprised of seeds dispersed into the area from nearby fruiting trees. Efficient dispersal of seeds from trees in nearby forest into deforested areas is therefore of paramount importance for natural forest regeneration to occur.

Are there other sources of forest regeneration besides seeds?

Some tree species can re-grow from old tree stumps or root fragments, years after the original tree was chopped down (Hardwick *et al.*, 2000). Dormant buds around the root collar of a tree stump can spontaneously sprout, often generating several new shoots. This is called coppicing. Both climax and pioneer tree species can re-grow in this way (de Rouw, 1993). Coppicing stumps have greater resilience to fire and browsing than seedlings. Drawing on food reserves stored in the roots, they can rapidly grow above surrounding weeds. Consequently, such regeneration can greatly accelerate re-establishment of tree cover. Protecting tree stumps, therefore, gives forest regeneration a head start, whereas destroying them delays it.

There is much variation among tree species in their ability to coppice and there is no adequate model to predict which species can coppice and which cannot. Larger stumps tend to produce more vigorous shoots, in greater numbers, than smaller stumps. Furthermore, taller stumps survive fire, browsing and weed competition better than shorter ones, since the shoots are usually above the height of disturbance.

In any deforested site, tree species regenerating from stumps represent a small proportion of the total original tree community of the former forest ecosystem. Although such trees can accelerate recovery of forest structure, seed dispersal is still essential to restore the tree species richness of the original forest.

Section 3 – The Importance of Seed Dispersal

What is the seed rain?

The seed rain consists of all seeds falling on to any particular area of land. It is often measured using seed traps, to capture seeds falling on to small, sample plots, of known area, and is expressed in terms of numbers of seeds, per metre squared, per month, often sub-divided by plant species, plant habit (tree, herb and so on) or dispersal mechanism. The density and species composition of the seed rain, on any deforested site, depends on the nearness of fruiting trees and on the efficiency of dispersal mechanisms. The seed rain is most dense and contains more tree species near to intact forest and is sparse in the centre of large deforested areas.

Most tree seedlings, establishing on large, deforested sites, germinate from seed either blown on to such sites by the wind or carried there by birds, bats or other animals. A depleted seed rain is one of the major causes of lack of forest regeneration or low species richness among the tree communities colonizing such sites. Encouraging seed dispersal is therefore a vital element of forest restoration.

How important is wind-dispersal of seeds?

In the forests of northern Thailand, dispersal of tree seeds by animals is more common than by wind. Of the 475 tree species recorded for Doi Suthep-Pui National Park, only 29% are wind-dispersed. In deciduous dipterocarp-oak forest, 44% of tree species (approximately 62% of individual trees) rely on the wind for seed dispersal. In contrast, in evergreen forests, only 21% of tree species (approximately 11% of individual trees) are wind-dispersed.

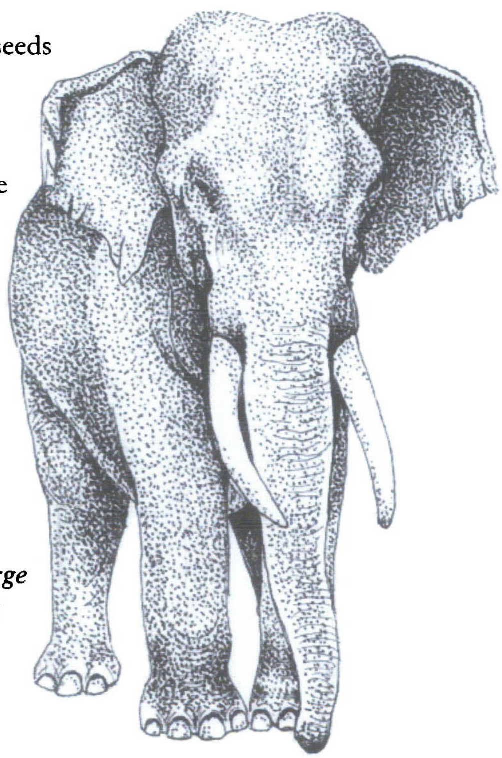
Wind-dispersed seeds tend to be small and light and often have wings, which slow their fall, enabling to them to drift over considerable distances. Therefore, wind-dispersed tree species can usually colonize deforested sites fairly easily. If existing conditions allow such species to become naturally established, there is no need to include them in tree planting programs.

What animals are seed dispersers?

Most tree species depend on animals to disperse their seeds. Some seeds become attached to fur or feathers and are transported on the outside of animals' bodies (termed "ectozoochorous" dispersal). More commonly, fruits are eaten and the seeds discarded or swallowed (dispersed whilst in the gut) and defaecated far away from the parent tree (termed "endozoochorous dispersal). Such fruits tend to be brightly coloured to attract animals, and fleshy, providing a reward of food to their animal dispersers.

Dispersal of seeds from forest into deforested sites, therefore, depends on animals that regularly move between the two habitats. Unfortunately, rather few forest animals venture out into open areas, for fear of exposing themselves to predators. Compared to wind, animals are rather inefficient seed dispersers. Apart from birds and bats, few animals travel very far between eating a fruit and defaecating the seed. Furthermore, many seeds are crushed by teeth or destroyed by digestive juices.

The maximum size of seeds dispersed by any animal species depends on the size of the animal's mouth. Whilst small animal species are still relatively common, larger ones, capable of swallowing large seeds whole, have been largely wiped out by hunting. Small seeds are therefore more easily dispersed into deforested areas by animals than larger ones.



Elephants can disperse very large seeds from forest into deforested areas.

In the past, large herbivores were undoubtedly the most important dispersers of seeds from forest into deforested areas. Elephants, rhinos and wild cattle often consume fruit in the forest, emerging into open areas at night to graze. With their large mouths and long roaming distances, such animals could swallow the largest of seeds and transport them over long distances. The elimination of most of these large mammals, over much of their former ranges in recent decades is now preventing dispersal of many tree species with very large seeds (Corlett and Hau, 2000).

Because they can fly, birds and bats can also disperse seeds over long distances. Amongst the birds, bulbuls are particularly important. They are common in forest and are frequent visitors to deforested sites, several kilometres from natural forest (Scott *et al.*, 2000). They disperse seeds of a very wide range of plant species (Sanitjan, 2001), up to 14 mm in diameter over long distances, since they retain seeds in their digestive tracts for up to 41 minutes (Whittaker and Jones, 1994). Other common bird species, which probably contribute to the seed rain of deforested areas, include mynahs, jays, magpies, thrushes, robins, chats, white-eyes, laughing thrushes and flowerpeckers (Corlett and Hau, 2000). Many of these are insectivores, which also take fruit as part of their diet. Near to intact forest, green pigeons, Oriental Pied Hornbill and, at higher elevations, wood pigeons probably play a role in seed-dispersal.

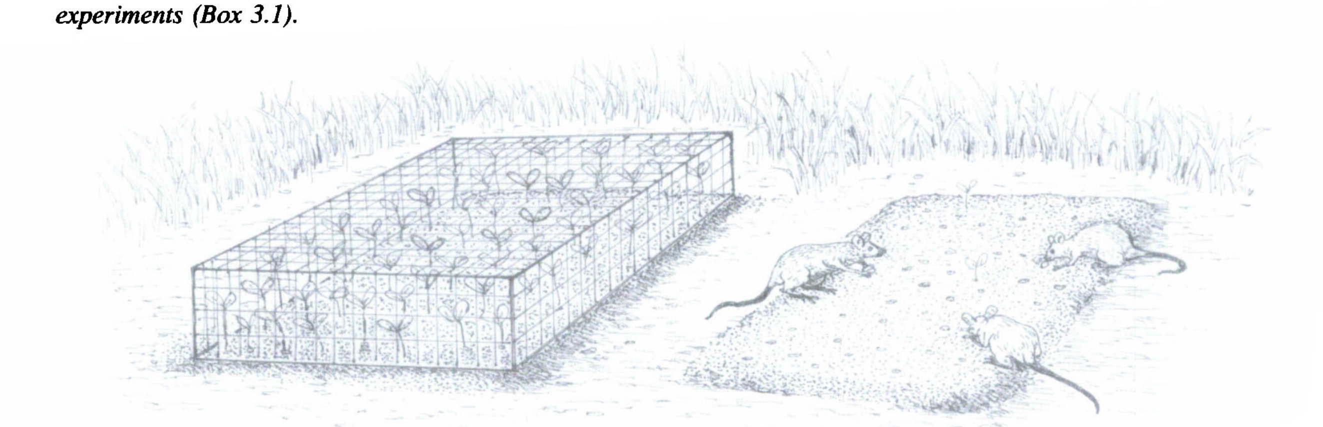
Fruit bats are important seed dispersers, since they fly over long distances and drop seeds in flight. However, unlike most birds, bats are nocturnal and cannot be identified using binoculars. Consequently, little research has been done on their role in forest regeneration. Research on bats is, therefore, a high priority for improvement of forest restoration techniques[1].

Non-flying mammal species that remain common and are likely to disperse seeds between forest and degraded areas include Common Wild Pig, Common Barking Deer, Hog Badger and various civet species, but again, largely due to their nocturnal habits, very little information is available on the seed dispersing capabilities of these animals.

How far are seeds dispersed?

Most tree seeds fall within a few metres of the parent tree. The density of a single tree's "seed shadow" declines steeply with distance away from the tree. However, according to Clark (1998), approximately 10 percent of tree seeds are dispersed over much longer distances of 1 to 10 km. Little is known about this long-distance component of the seed rain, since it is very difficult to measure. However, it is an important consideration in the design of forest restoration projects, particularly with respect to the distance of forest restoration plots from intact forest and how this will affect recovery of tree species richness.

Rats are major seed predators in deforested areas in northern Thailand. Their impact on seed survival has been measured by caged exclusion experiments (Box 3.1).



[1]The Chiang Mai Research Agenda for the Restoration of Degraded Forestlands for Wildlife Conservation in Southeast Asia, Part 7 of Elliott, S., J. Kerby, D. Blakesley, K. Hardwick, K. Woods and V. Anusarnsunthorn (eds.), *Forest Restoration for Wildlife Conservation.* Chiang Mai University (2000).

SECTION 4 - SEED PREDATION

If seeds deposited in deforested areas are to germinate, they must avoid being killed by animals. A single tree produces vast numbers of seeds during its lifetime, although, to replace itself, it need produce only one that eventually grows into a reproductively mature adult. The need for such excessive seed crops is because most seeds either fall where conditions are unfavorable for germination or they are destroyed by animals. Because many seeds contain rich reserves of oils and carbohydrates, they often end up becoming nutritious meals for animals. Whilst some seeds may pass through the digestive tracts of animals intact, many others are crushed by teeth and digested.

What is seed predation?

Seed predation is the destruction of a seed's potential to germinate when an animal crushes or digests its embryo. It can occur when seeds are attached to the parent tree (pre-dispersal predation). However, seed predators have more impact on forest regeneration when they attack seeds that have already been dispersed into deforested areas (post-dispersal predation).

What animals are seed predators in regenerating forest?

Small rodents and insects, particularly ants, are major seed predators. In deforested areas in northern Thailand, rats and mice such as *Mus pahari, M. cookie, Rattus bukit, R. koratensis, R. surifer* and *R. rattus* are the most prevalent rodent seed predators. These animals are more common in deforested sites than in forest (Sharp, 1995). If forest regeneration progresses to the point of canopy closure, rodent populations decline markedly (Thaiying, 2003). Therefore, tree planting reduces seed predation.

Ants have been recognised as major seed predators in Central and South America (Nepstad *et al.*, 1996), but their potential impact on forest regeneration in Asia is only just becoming apparent (Woods and Elliott, 2004). More research is needed on the seed-eating habits of ants in deforested areas in Asia.

What levels of seed predation can be expected in deforested areas?

In the tropics, more than 90% of tree species have more than 50% of their seeds killed by animals or fungi. Seed predation has a significant effect on both the distribution and abundance of tree species. It is also a potent evolutionary force, compelling trees to evolve various morphological and chemical mechanisms to defend their seeds against animal attack *e.g.* poisons, tough seed coats and so on.

Levels of seed predation are highly unpredictable, varying from 0 to 100 percent, depending on tree species, vegetation, location, season and so on. In general, however, seed predation in deforested areas is usually severe enough to significantly reduce seed survival of most tree species (see Box 3.1 & Hau, 1999).

What determines the susceptibility of seeds to predation?

Ecological theory suggests that the susceptibility of any particular tree species to seed predation depends on the food value of its seed. Animals should consume seeds that provide them with maximum nutriment, whilst requiring the least effort to find them.

Most attention has been paid to the influence of seed size on vulnerability to predation. Large seeds provide large food rewards to those seed predators that are capable of processing them. Animals may be able to locate large seeds easily, since they are more visible and emit more odour than small seeds, but small rodents have difficulty handling very large seeds. In contrast, small seeds have low food value and are easily overlooked. Vongkamjan (2003) confirmed this effect of size on tree seed predation in evergreen forest clearings in northern Thailand. She observed seed predation rates of zero for all tree species tested which had small seeds (seeds weighing less than 0.01 gm); 50-91 percent for 4 of 10 medium-sized seed species (0.01 – 0.2 gm; the others had removal rates of less than 1%) and 63-100% for 6 of 10 large-seeded species (0.2 – 6.2 gm; four others had removal rates of less than 2%).

Box 3.1 - Forest Tree Seed Predation in Northern Thailand

The effects of seed predation by rodents can be measured by placing seeds inside wire-mesh cages, to exclude rodents. Germination of seeds inside the cages is then compared with that of seeds placed outside cages nearby and exposed to predation.

Using this technique in a medium-sized clearing (about 50 m across), surrounded by evergreen forest in Doi Suthep-Pui National Park, Hardwick (1999) found that the mean germination percentages of 8 out of 12 tree seed species, exposed to predation were reduced by 50% or more, compared with seeds protected within cages (*i.e. Castanopsis acuminatissima, Engelhardia spicata, Eurya acuminata, Helicia nilagirica, Hovenia dulcis, Prunus cerasoides, Schima wallichii* and *Styrax benzoides*). Only the tiny seeds of *Morus macroura* escaped significant predation, perhaps because rodents are unable to find them.

Similarly, in small tree-fall gaps nearby, Vongkamjan (2003) recorded seed predation rates of 100% for *Irvingia malayana* and *Elaeocarpus prunifolius*, 91% for *Reevesia pubescens*, 88% for *Terminalia chebula*, 77% for *Shorea obtusa*, 73% for *Terminalia mucronata*, 69% for *Terminalia bellirica*, 65% for *Macropanax dispermus*, 63% for *Elaeocarpus lanceifolius* and 50% for *Acrocarpus fraxinifolius*. Again, tree species with zero seed predation were those with tiny or medium-sized seeds *e.g.* all *Ficus* spp, *Morus macroura, Betula alnoides, Debregeasia longifolia, Saurauia roxburghii, Eurya acuminata, Vaccinium sprengelii, Trema orientalis, Tetradium glabrifolium, Lagerstroemia speciosa etc.*

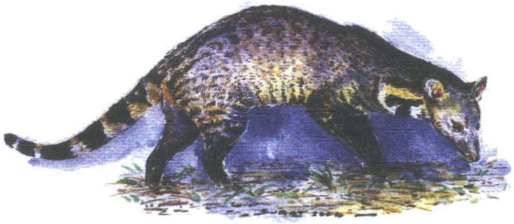
In contrast, in a much larger area of abandoned agricultural land at a similar elevation on the same mountain, Woods and Elliott (2004) found no significant seed predation of six tree species (*i.e. Sapindus rarak, Lithocarpus elegans, Spondias axillaris, Erythrina subumbrans, Gmelina arborea* and *Prunus cerasoides*) by rodents, although predation by ants was high on the latter four species.

The longer a seed lies on the ground before germinating, the higher is the probability that a predator will discover it. Rapid germination reduces the period during which seed predation can occur. Hardwick (1999) reported a positive relationship between length of seed dormancy and seed predation rates in evergreen forest clearings in northern Thailand.

The nature of the seed coat is important in protecting seeds from predation. A tough, thick and smooth seed coat makes it very difficult for rodents to reach the nutritious seed contents. Low predation rates amongst seeds with thick or hard seed coats have been reported for many Asian forest tree species (*e.g.* Hau, 1999; Vongkamjan, 2003). However, there may be a trade-off between seed coat thickness and length of dormancy in their effects on seed predation. A thick seed coat often causes prolonged dormancy, which lengthens the period during which seeds are available for attack by predators. But, even the toughest seed coat must soften, just before germination, presenting a window of opportunity for seed predators. Vongkamjan (2003) observed that several hard-coated tree seed species were attacked during this vulnerable period.

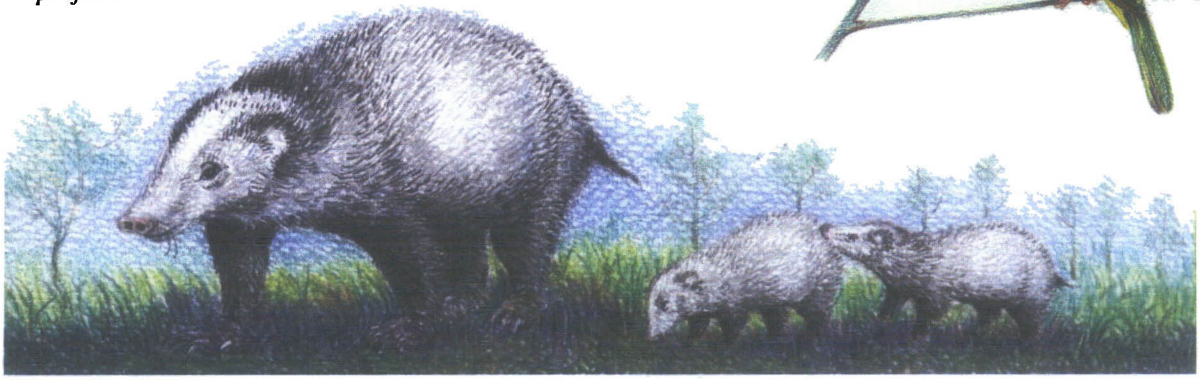
Dispersal pattern may also affect likelihood of predation. Seeds that are scattered thinly over a large area (a pattern that often results from wind-dispersal) are hard to find by predators, whereas a clumped dispersal pattern (characteristic of animal-dispersal) means that once one seed has been discovered, the whole clump will probably be predated. Sporadic large fruit crops, such as those produced by masting or monocarpy (Section 2, this part) satiate seed predator populations. Seed predators cannot possibly eat all the seeds, so many seeds escape predation.

Models capable of predicting the overall effects of seed predation on forest regeneration have proved elusive. The literature is full of contradictory statements and opposing viewpoints. The effects of seed predation undoubtedly depends on complex interactions among many variables, including the nature of the environment, availability of alternative food sources and the individual preferences and seed handling capabilities of the particular seed predator species present. It is certainly a factor that must be considered in forest restoration projects that involve direct seeding, but its effects must be evaluated for each individual site.



SEED DISPERSERS & SEED DESTROYERS

Small and medium-sized seed-dispersing animals, such as the Hog Badger, (Arctonyx collaris) *(below), Large Indian Civet* (Viverra zibetha) *(above) and Flavescent Bulbul* (Pycnonotus flavescens) *(right) can remain common even in highly fragmented forest landscapes. They can disperse seeds over long distances from forest into large deforested areas. Preventing hunting of them is a vital component of forest restoration projects.*



The Chestnut Rat (Rattus bukit) *(below) rarely disperses seeds, but usually destroys them. They are more common in deforested areas than in closed forest.*

Other seed-dispersers, such as the White-Handed Gibbon (Hylobates lar) *(above left) and the Indian Pied Hornbill* (Anthracoceros albirostris) *(above center) rarely leave dense forest and so are unlikely to contribute much to the seed rain of open, deforested areas.*

Peter Schwendinger

Often feeding on fallen fruits in the forest during the day time and emerging at night to browse in clearings, the Sumatran Rhino was the perfect seed disperser for forest regeneration. Now, sadly, this species has been extirpated from northern Thailand and several other large animals, such as elephants and wild cattle have been reduced to such low populations that they no longer play a significant role in seed dipsersal.

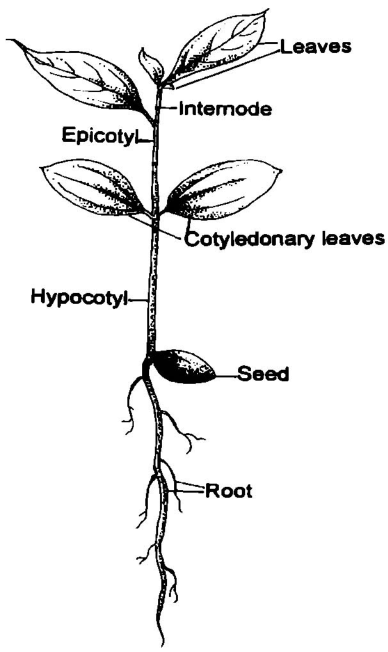
The Competition

Deforested sites in northern Thailand are usually dominated by aggressive, fire-resilient grasses and herbs, which often grow above head-height (left). Many are exotic weeds, which are particularly successful at invading and persisting in degraded areas. These fast-growing plants prevent tree establishment by smothering tree seedlings; by absorbing most of the soil moisture and nutrients that would otherwise be available for tree growth and by providing fuel for fires.

Common herbaceous weed species in degraded sites include several exotic species such as (A) Eupatorium odoratum, *(B)* Eupatorium adenophorum, *(C)* Crassocephalum crepidioides *and (E)* Tithonia diversifolia *(Mexican Sunflower) as well as dominant native grasses such as (D)* Saccharum arundinaceum, (F) Pennisetum polystachyon *and* (I) Phragmites vallatoria. *Vines such as (G)* Dioscorea bulbifera *smother tree seedlings, whilst the shrub (H)* Clerodendrum fragrans *shades them from above. Bracken fern (J)* Pteridium aquilinum *is found all around the world.*

SECTION 5 – GERMINATION

The transition from seed to seedling is a dangerous time in a tree's life. Seed dormancy must end and appropriate levels of moisture and light must exist to trigger germination. Because of its small size, low energy reserves and low photosynthetic capability, a young seedling is very vulnerable to changes in environmental conditions, competition from other plants and attack by herbivores. A single caterpillar can completely destroy a young seedling in a few minutes, whereas larger plants are more resistant to attack.



What is seed dormancy?

After being deposited in a deforested site, a seed might not germinate immediately, even where conditions for germination are optimal. Dormancy is the period between seed dispersal and germination. During dormancy, some seeds undergo maturation or chemical changes that prepare the seed for germination. Dormancy enables seeds to survive the rigours of dispersal and germinate when conditions are most favourable for seedling establishment.

How long do seeds lie dormant?

In any batch of seeds, the length of dormancy of individual seeds can be variable. The most convenient overall measure of dormancy is the number of days between seed sowing and germination of half the total seeds that eventually germinate. This is the "median length of dormancy" (MLD). For example, if 9 seeds eventually germinate out of 100 sown, MLD would be the number of days between seed sowing and germination of the 5th seed.

Seeds of most tropical tree species have short dormancy periods. In a sample of 262 forest tree species examined from Doi Suthep-Pui National Park, 43% had MLD's of less than 30 days, whilst only 21% had MLD's of more than 100 days. Tree species with the shortest MLD's were *Albizia odoratissima*, *Erythrina subumbrans* and *Quercus lanata* (all 7 days). *Elaeocarpus bracteanus* had the longest recorded MLD of 787 days (FORRU-CMU, original data, 2003).

When is the best time for seed germination?

Many factors determine the optimal period for germination (*e.g.* temperature, avoidance of seedling predators and so on). However, in the seasonally dry tropics, soil moisture appears to be the overriding factor. The optimal time for tree seed germination is the start of the rainy season. Seedlings establishing then have the full length of the rainy season to grow their roots deep into the soil and to build up energy reserves before onset of the dry season. A deep root system allows seedlings to tap into stored soil moisture that will enable them to survive the dessicating heat of their first dry season. Another reason for germination at the start of the rainy season is the release of nutrients from litter. Moisture encourages decomposition and, where they occur, fires also release nutrients.

Optimal seed dispersal time varies greatly among tree species. The length of time required to develop a mature fruit from a fertilised flower and the availability of dispersal agents are just two species-specific characteristics that determine optimal seed dispersal time. Different lengths of seed dormancy amongst different tree species allow tree species to disperse their seeds at different times throughout the year, whilst maintaining a peak in germination around the beginning of the rainy season. FORRU's research on this topic is presented in Box 3.2.

Box 3.2 – Seed dormancy links optimal dispersal time with optimal germination time.

Different forest tree species produce seeds at different times of the year, but different seed dormancy lengths, amongst the species, ensures that, whenever seeds are produced, most species germinate at the start of the rainy season.

A study of seed dispersal and germination of 262 tree species collected in the forests of Doi Suthep-Pui National Park, (FORRU-CMU, original data, 2003) found that most seeds collected in the late dry and early rainy seasons germinated rapidly (>90% had MLDs of <71 days). In contrast, for seeds collected in the late wet and early rainy seasons, only 48.5% and 54.8% of species, respectively, germinated rapidly (MLDs <71 days). The others remained dormant for long periods. Consequently, the median seed of 75.8% of species studied germinated in the late dry or early rainy seasons.

This timing allows maximum seedling development to occur before onset of the dry season and minimises the period that seeds lie dormant on the forest floor, consuming energy by respiration and at risk from seed predators.

Species could be grouped according to dispersal time and dormancy syndromes. The 'rapid-rainy group' was comprised of 171 species, which dispersed their seeds late in the dry season and during the rainy season. These species germinated rapidly in the rainy season. In contrast, the 'delayed-rainy group' was comprised of 62 species, which dispersed their seeds late in the rainy season and early in the dry season. They had prolonged dormancy, resulting in germination in the subsequent rainy season. Another distinct group, the 'rapid-dry group' had 34 species, which dispersed their seeds in the early dry season and germinated rapidly in the same season. The survival strategies of this latter group deserve further research.

A very similar pattern of seed dispersal and germination was observed in Panama by Nancy Garwood (1983), suggesting that seasonally dry tropical forests on at least two separate continents have evolved similar strategies to overcome the common constraints imposed by annual cycles of wet and dry.

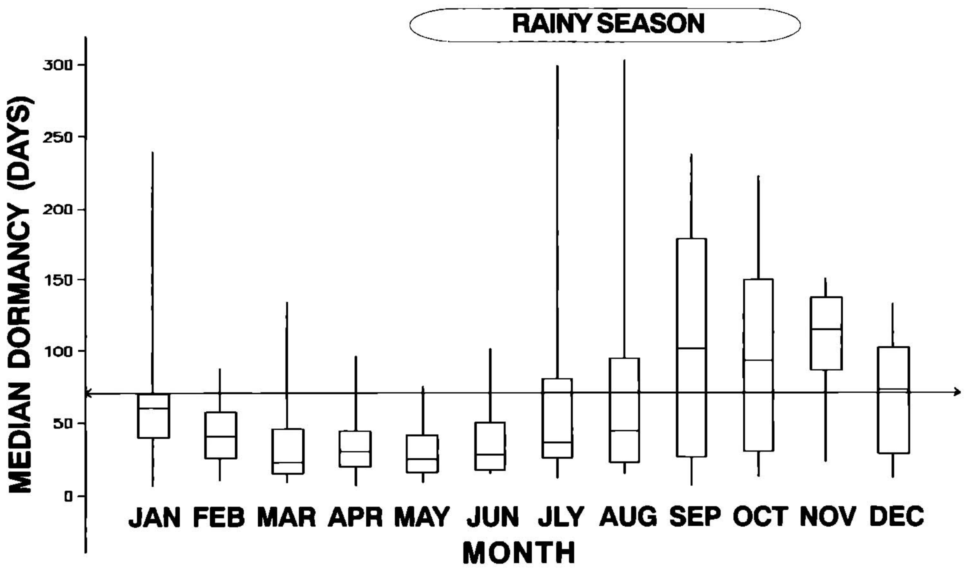


Figure 3.3 - The relationship between median length of dormancy (MLD) and the month of seed dispersal of forest tree species in Doi Suthep-Pui National Park. Each box represents 50 % of the number of tree species dispersed in each month. The horizontal line within each box indicates the median value of all MLDs, averaged across all species dispersed in each particular month, whilst extreme values are indicated by the thin vertical lines.

What conditions are required for seed germination?

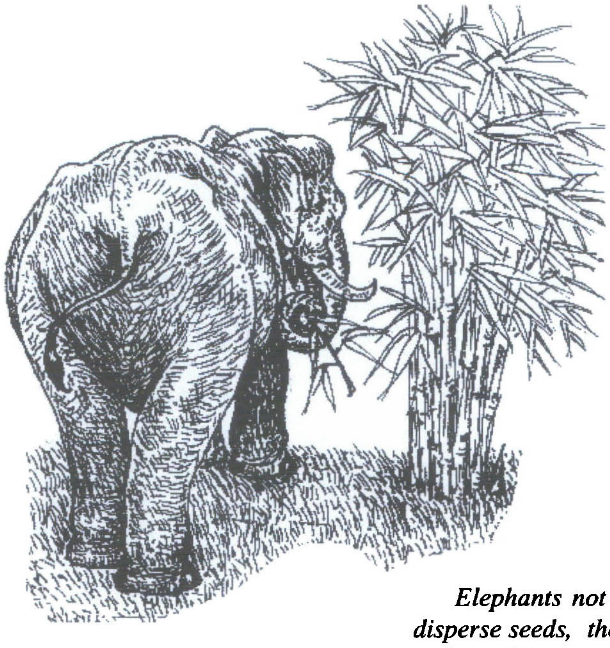
Seed germination depends on many factors, the most important of which are sufficient soil moisture and light conditions, not only total light levels, but also the quality of the light.

Within intact forest, the species of tree seedlings that establish in any small, tree-fall, gap depends initially on the species composition of the seed rain and subsequently on the micro-climatic conditions within the gap. The latter depend on the size, shape and aspect of the gap and the density and height of the trees that surround it. Which seed species fall into a gap depends on which tree species are seeding near-by and on the chance events that affect dispersal mechanisms. Subsequently, gap-dependent conditions selectively favour or eliminate the species present, according to the micro-climatic requirements of each species.

Large, deforested sites, dominated by dense weeds present a far more hostile environment to tree seeds. Temperatures fluctuate dramatically between night and day. Humidity is lower, wind speeds are higher and soil conditions are much harsher.

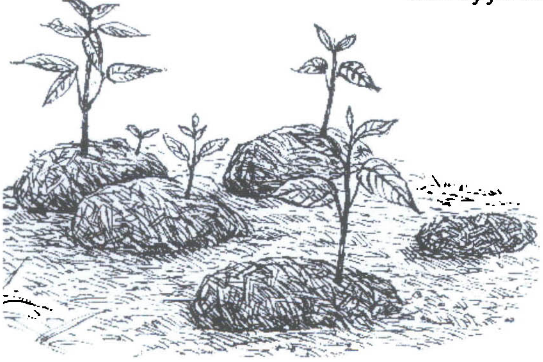
Many seeds become trapped in the weed canopy, where they dry out and die, never to reach the soil. Even for seeds that fall through the weed canopy, weeds present another problem. A high ratio of red to far red light in the spectrum stimulates seed germination in many pioneer tree species, particularly those with small seeds (Pearson *et al.*, 2003). By absorbing proportionately more red light than far red light, a dense green canopy of weed foliage removes this vital stimulus.

Therefore, seed germination of most forest tree species depends on the presence of so-called "germination micro-sites", where conditions are more favourable. These are tiny sites with reduced weed cover and sufficient soil moisture to induce seed germination. They include decaying termite mounds, rocks covered in moss and especially rotting logs. The latter provide an excellent moist and nutrient-rich medium for seed germination and are usually weed free.



Elephants not only disperse seeds, they may also enhance germination of some species...

...and provide them with a generous dose of fertilizer.



Do animals enhance germination?

Passage of seed through an animal's gut can affect both total germination percentage and the rate of germination. These properties can be enhanced, inhibited or unaffected. For most tropical trees, passage through an animal has no overall effect on germination, but for those species showing a response, germination is enhanced more often than it is inhibited. Travaset (1998) reported that ingestion by animals increased germination percentage of 36% of tree species tested, whilst it reduced germination percentage for only 7%. Seeds of 35% of tree species tested germinated more rapidly after passage through an animal's gut, compared with only 13% that had more delayed germination. Responses are highly variable. Seeds of species within the same genus, or even from different individual plants of the same species, can have different responses.

SECTION 6 – SEEDLING ESTABLISHMENT

After a seed has germinated, the greatest threats to seedling survival in deforested areas are fire and competition with weeds. Deforested areas are usually dominated by fire resilient, herbs and grasses. By absorbing most of the sunlight and draining the soil of moisture and nutrients, these rapidly growing weeds leave few resources for slower growing tree seedlings. However, tree seedlings may enlist the help of beneficial mycorrhizal fungi in their battle to survive and grow above the weed canopy.

What are the most common weeds in deforested sites?

In the mountains of northern Thailand, grasses in tough tussocks, up to 4-5 m tall, often dominate deforested sites (*e.g. Imperata cylindrica, Microstegium vagans, Panicum notatum, Phragmites vallatoria, Setaria palmifolia, Thysanolaena latifolia etc.* (Gramineae)). Since their growing points are protected from fire by sheaths of toughened leaves, these grasses thrive in fire-prone areas. Looking similar to grasses (but with triangular stems) sedges are also a major comp-onent of the weed communities on deforested sites (*e.g. Cyperus cyperoides, Rhynchospora rubra, Scleria levis* and so on (Cyperaceae)).

Many weeds are introduced exotic species such as the shrubby-herbs *Eupatorium odoratum* and *E. adenophorum* (Compositae). Species in this family (the daisy family) are particularly success-ful at colonizing deforested sites. They produce tiny fruits (achenes) either topped with a para-chute of fine hairs, for drifting on the breeze, or armed with hooks, which attach to the fur of passing animals (*e.g. Artemisia indica, Ageratum conyzoides, Bidens pilosa, Conyza sumatrensis* and so on). Found all round the world, the hardy bracken fern (*Pteridium aquilinum* (Dennstaedtia-ceae)) also dominates vast expanses of treeless hills. It forms a dense canopy, impenetrable to incoming seeds and its dried fronds are a serious fire hazard.

Evergreen vines *e.g. Shuteria involucrata, Clitoria mariana, Dioscorea* spp *etc.* and woody climbers *e.g. Millettia pachycarpa* (all Leguminosae, Papilionoideae) can inhibit forest regeneration by smothering tree seedlings, whilst shrubs, such as *Boehmeria chiangmaiensis* (Urticaceae), *Clerodendrum fragrans* (Verbenaceae) and *Triumfetta pilosa* (Tiliaceae) represent more advanced regen-eration.

Rotting logs provide excellent germination sites for tree seeds. Relatively free of competition from weeds, the decomposing wood preserves moisture and has excellent structure as a germination medium.

How do weeds prevent forest regeneration?

Light-demanding, herbs rapidly exploit the soil and develop a dense canopy, which absorbs almost all light available for photosynthesis. Amongst such fast-growing plants, small tree seedlings are starved of light, moisture and nutrients. Since trees have evolved to grow tall, they must expend considerable energy and carbon to produce the woody substance, lignin, in order to support their future massive size against gravity. Free of the need to make lignin, herbs can grow much faster than trees. Only when a tree's canopy overtops the weeds and its root system penetrates deeper into the soil than the shallower roots of the weeds does a tree gain an unbeatable advantage over the herbs. Unfor-tunately, most tree seedlings fade away in the shade of the weeds long before they reach that stage.

Weeds also prevent forest regeneration by providing fuel for fires in the dry season. Most herbaceous weeds survive fire as seeds, corms or tubers, buried in the soil, or they possess well-protected growing points (*e.g.* grasses, cycads, phoenix palms) that resprout after fire. In trees, the growing points are raised on the tips of branches. In a fire, therefore, the small seedlings or saplings of trees are often completely incinerated by the blazing dried weeds surrounding them.

Does weed community structure affect tree establishment?

Some dominant weed species seem to favour forest regeneration more than others. For example, in weed communities dominated by different herb species in Doi Suthep-Pui National Park, Adhikari (1996) found that sites dominated by the shrubby herb, *Eupatorium adenophorum,* supported the highest density and diversity of forest tree seedlings. The tree seedlings established there had higher growth rates and lower mortality rates than in sites dominated by grasses such as *Imperata cylindrica* and *Phragmites vallatoria* or by bracken fern (*Pteridium aquilinum*). Weed communities dominated by bracken seemed particularly resistant to colonization by forest trees.

Could lack of mycorrhizae limit forest regeneration?

Almost all tropical tree species develop symbiotic relationships with fungi that infect their roots to form mycorrhizae (literally "fungus-roots"). Such relationships provide many benefits to host trees and are especially important in enabling seedlings and saplings to out-compete weeds.

There are two main types of mycorrhizae. Ecto-mycorrhizae (EM) have a sheath of fungal tissue around the tree roots, whereas vesicular-arbuscular mycorrhizae (VAM) lack such a sheath. Almost all tropical tree species form VAM, whereas EM are more restricted to a few unrelated tree families such as the Dipterocarpaceae, Fagaceae, Pinaceae and Caesalpinioideae. EM are favoured by seasonally dry conditions.

The most important advantage to trees from mycorrhizae is increased uptake of mineral nutrients, especially phosphorus, which is lacking in tropical soils. Because fungal strands are so much finer that plant roots, they ramify through the soil much more densely, reaching nutrients that thicker tree roots alone cannot reach. Mycorrhizae improve growth and survival of tropical trees. They have also been shown to increase drought resistance, disease resistance and water uptake of their host plants; all benefits that can help trees become established in the harsh conditions of deforested sites.

Could a lack of mycorrhizal fungi inhibit colonization of deforested sites by some tree species? Within dense forest, transmission of most VAM fungi occurs directly between tree roots. Concentrations of fungal spores in the soil are usually very low. For fungus species, which produce above-ground fruiting bodies, spores are dispersed by the wind, but those with under-ground fruiting bodies rely on small rodents and other animals, which eat the spore-laden fruiting bodies and disperse viable spores via their faeces. Therefore, it is very unlikely that even very large deforested areas are completely devoid of all mycorrhizal fungal spores.

However, the question of whether mycorrhizal fungi of the required species are present in sufficiently high densities to infect newly establishing forest tree seedlings warrants further scientific research.

Too many domestic cattle, such as water buffalo, prevent forest regeneration by eating and trampling young trees and seedlings...

One of the most beneficial effects of cattle can be weed reduction. By grazing on herbaceous weeds, cattle decrease competition for tree seedlings. In addition, domestic cattle can act as seed-dispersers, in the same way as wild cattle can, if they have access to fruits from nearby forest trees. Furthermore, their hoof prints can provide microsites for seed germination, where moisture and nutrients accumulate and weeds have been crushed.

The most obvious disadvantage of cattle is that they browse on tree saplings. Cattle can be very selective, often eating the foliage of palatable tree species, whilst ignoring that of unpalatable ones. Distasteful or thorny trees, can thus become dominant, whilst edible ones gradually disappear from the regenerating forest. Cattle also trample young seedlings, indiscriminately and, where large herds follow regular paths, soil compaction can become a problem.

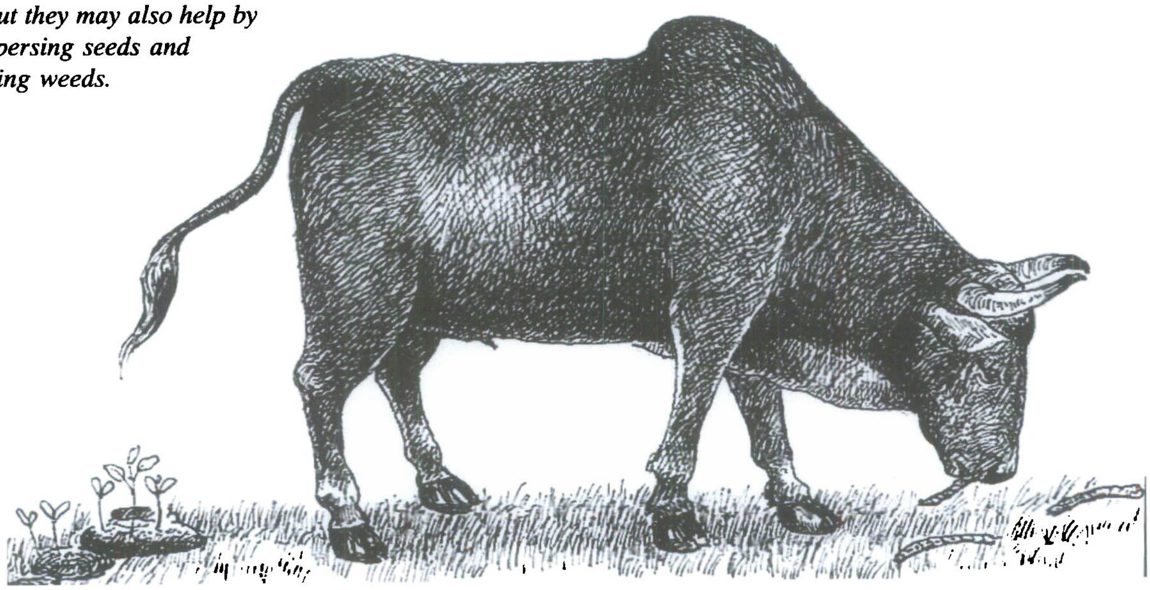
The balance between these positive and negative effects and their relationship with herd density are not fully understood. Furthermore, the effects of cattle on forest regeneration vary greatly with site conditions and vegetation type. Therefore, further research is required to develop models that might be able to predict the overall effects of cattle on forest regeneration at any particular site.

Do seedlings have predators?

In most areas, large herbivores like elephants and wild cattle, which could destroy a tree seedling with a single bite, are now so rare that they have no significant impact on forest regeneration at the landscape level. Domestic cattle, on the other hand can be a major impediment to natural forest regeneration.

In most tropical countries, it is common to find cows or water buffaloes ranging freely across degraded forestland. The effects of domestic cattle on natural forest regeneration depend on their population density. A small herd might have no significant impact or might even be beneficial in some areas, but where cattle populations are dense, their negative effects usually outweigh any positive effects.

...but they may also help by dispersing seeds and eating weeds.



SECTION 7 – THE ECOLOGY OF FIRE

In the seasonally dry tropics, fires during the hot season are a major constraint to forest regeneration. By the end of the rainy season, weedy vegetation has often grown above head height and is practically impenetrable. In the hot season, this vegetation dies back, dries out and becomes highly flammable. Each time it burns, any tree seedlings that may have managed to gain a root-hold amongst the weeds are usually killed, whereas the weeds survive, re-growing from root stocks or seeds protected beneath the soil. Therefore, the vegetation creates conditions conducive to fire and prevents establishment of trees that could shade out the weeds. Breaking this cycle is the key to restoring seasonally dry tropical forests.

Is fire a natural occurrence in seasonally dry tropical forest?

Fires can be started naturally by lightning strikes, but such natural fires usually occur several years or decades apart. This allows plenty of time for trees to grow large enough to develop some resilience to burning. However, these days, most fires are started by humans. Fires, set to clear fields for cultivation, often spread into surrounding areas, burning young trees and preventing forest regeneration. In many instances, fires are started deliberately to make mushrooms easier to find and to encourage growth of grasses for livestock grazing and to attract wild animals for hunting.

How do fires prevent forest regeneration?

Studies that have compared frequently burnt areas with those protected from fire show that preventing fires accelerates forest regeneration. Meng (1997) and Kafle (1997) compared an area of deciduous dipterocarp-oak forest, protected from fire for 27-28 years with an adjacent frequently burnt area, on the lower slopes of Doi Suthep near Wat Palaht (520 m elevation). They found that frequent fires reduce both the density and species richness of the tree seedling community, as well as the seed rain (by killing seed-producing trees) and the accumulation of viable seeds in the soil seed bank.

Fire burns off soil organic matter, leading to a reduction in the soil's moisture holding capacity. The drier the soil, the less favourable it is for germination of tree seeds. Burning also reduces soil nutrients. Calcium, potassium and magnesium are lost as fine particles in smoke, whilst nitrogen, phosphorus and sulphur are lost as gases. By destroying the vegetation, fire increases soil erosion by 3-32 times. It also kills beneficial soil micro-organisms, especially mycorrhizal fungi and microbes which break down dead organic matter and recycle nutrients.

Doesn't fire encourage seed germination?

In some ecosystems, fire stimulates seed release and germination, but this effect has not yet been found in the seasonally dry tropical forests of northern Thailand. Hardwick (unpub.) tested the effects of fire on germination by placing seeds of twelve tree species, from deciduous forest on Doi Suthep, in burning newspaper at a similar temperature to that of a mild litter burn. Seeds of seven of these species were all killed, whilst germination of the others was substantially reduced.

Does fire kill trees?

Most small tree seedlings and sapling are killed by fire, but the larger a tree becomes, the more likely it is to survive. Larger trees have thicker bark, which insulates their vital vascular system (the cambium layer) from the scorching temperatures of forest fires. Stored food reserves in the roots enable larger trees to grow back rapidly, even if their above-ground parts are burned away. The minimum size at which a tree can survive a wild fire varies among species, but as rough rule, a root collar diameter larger that 5 cm usually enables most tree species to survive a moderate burn.

SECTION 8 – THE SURVIVORS

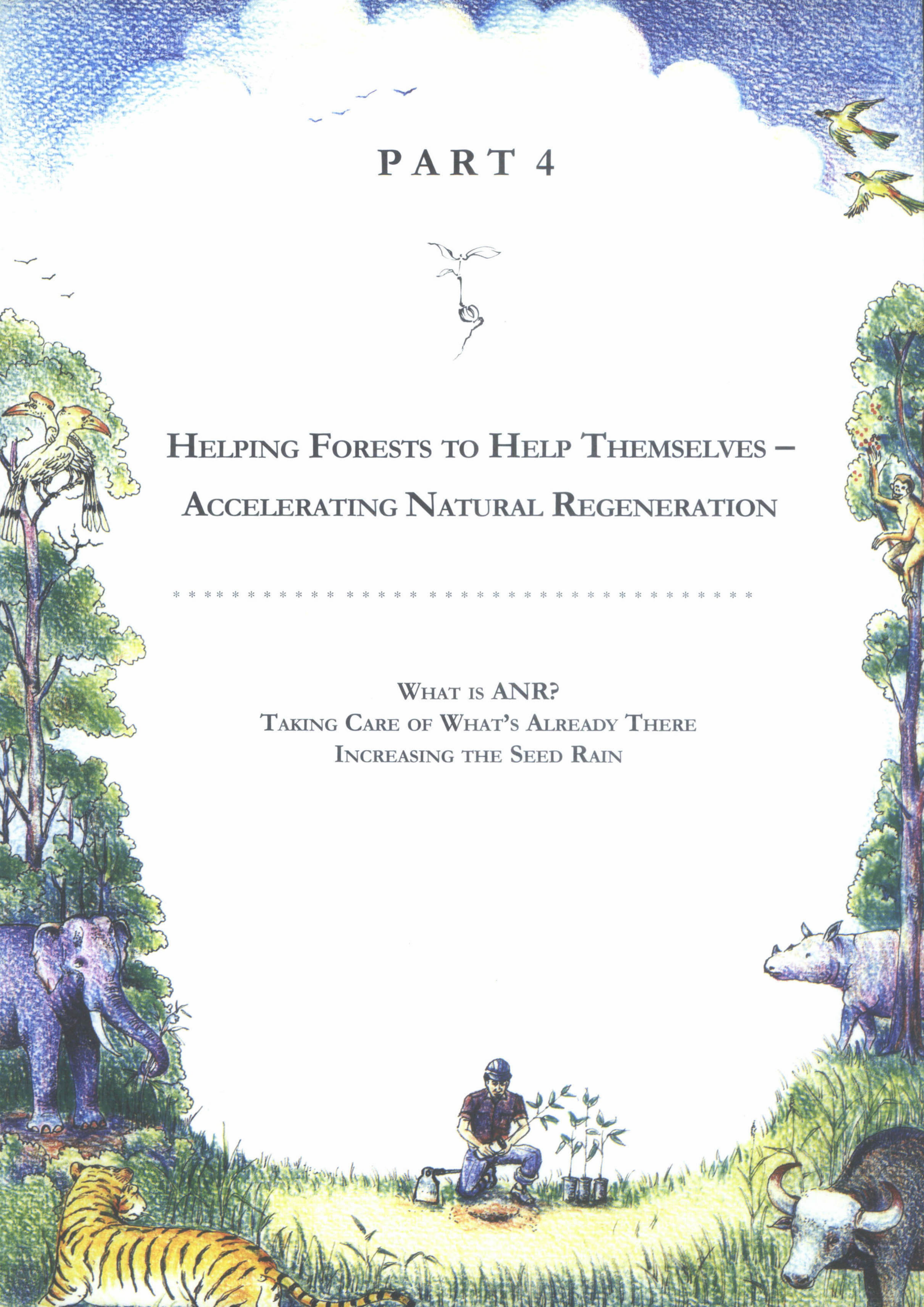
To summarise; it is very difficult for most forest tree species to re-colonize large deforested areas that have become dominated by weeds, mostly because of continued disturbance by humans. Lack of seed sources, disappearance of seed-dispersing animals, competition with hardy, often exotic, weeds and frequent fires all prevent enough tree species establishing at sufficiently high densities to restore the original forest ecosystem. However, a few tree species can overcome these constraints and some of the more common ones, found colonizing large deforested areas in Doi Suthep-Pui National Park, are listed in the table below. Many are deciduous tree species, which grow over a wide range of elevations, and most have small seeds that are easily dispersed by small birds or wind. Where remnant, mature trees of these species still survive in the landscape, there is usually no need to include them in tree planting projects; but wherever they have been eliminated, they are obviously very suitable for planting in degraded areas, especially if mixed with some of the framework tree species described in Part 9.

Table 3.1 – Common tree species observed establishing in open deforested sites at 1,300 m elevation in northern Thailand (FORRU, original data, 2003).

Species	Family	Elevation (m)	Leafing Phenology[1]	Seed Size Class[2]	Seed Dispersal[3]
Albizia odoratissima (L. f.) Bth.	Leguminosae, Mimosoideae	350-1525	D	M	W
Alstonia scholaris (L.) R. Br. var. *scholaris*	Apocynaceae	350-1150	D	M	W
Antidesma acidum Retz.	Euphorbiaceae	400-1525	D	M	A
Aporosa dioica (Roxb.) M.-A.	Euphorbiaceae	475-900	D	M	A
Aporosa villosa (Lindl.) Baill.	Euphorbiaceae	500-1500	D	M	A
Aporosa wallichii Hk. f.	Euphorbiaceae	500-1400	D	M	A
Dalbergia cultrata Grah. *ex* Bth.	Leguminosae, Papilionoideae	350-700	D	L	W
Dalbergia stipulacea Roxb.	Leguminosae, Papilionoideae	500-1400	D	L	W
Debregeasia longifolia (Burm. f.) Wedd.	Urticaceae	525-1685	E	S	A
Dillenia parviflora Griff. var. kerrii (Craib) Hoogl	Dilleniaceae	375-1000	D	M	A
Engelhardia spicata Lechen. *ex* Bl.	Juglandaceae	850-1650	D	M	W
Eugenia albiflora Duth. *ex* Kurz	Myrtaceae	800-1525	E	L	A
Ficus hirta Vahl var. *hirta*	Moraceae	350-1150	E	S	A
Ficus hispida L. f. var. *hispida*	Moraceae	350-1525	ED	S	A
Glochidion sphaerogynum (M.-A.) Kurz	Euphorbiaceae	600-1100	D	S	A
Litsea cubeba (Lour.) Pers.	Lauraceae	1100-1685	E	M	A
Markhamia stipulata (Wall.) Seem. *ex* K. Sch.	Bignoniaceae	950-1550	D	M	W
Myrica esculenta B. -H. ex D. Don	Myricaceae	1300-1500	E	S	A
Phoebe lanceolata (Wall. *ex* Nees) Nees	Lauraceae	550-1550	E	L	A
Phyllanthus emblica L.	Euphorbiaceae	600-1620	D	M	A
Pterocarpus macrocarpus Kurz	Leguminosae, Papilionoideae	350-900	D	M	W
Schima wallichii (DC.) Korth.	Theaceae	600-1620	E	M	W
Sterculia villosa Roxb	Sterculiaceae	600-1575	D	M	W
Stereospermum colais (B.-H. *ex* Dillw.) Mabb.	Bignoniaceae	900-1275	D	S	W
Styrax benzoides Craib	Styracaceae	600-1650	E	L	A
Trema orientalis (L.) Bl.	Ulmaceae	1050-1500	ED	M	A

[1]E = evergreen; D = deciduous; ED = evergreen/deciduous (tropophilous)
[2]S= small<0.01 g (dry mass); M= medium 0.01-0.2 g and L= large > 0.2 g
[3]W= dry fruits mostly dispersed by wind; A= fleshy fruits mostly dispersed by animals, especially small birds

The next obvious question is: how can the many factors that hinder forest regeneration be overcome? We address this crucial issue in Part 4.



PART 4

Helping Forests to Help Themselves – Accelerating Natural Regeneration

* *

What is ANR?
Taking Care of What's Already There
Increasing the Seed Rain

No Tree Planting Necessary?

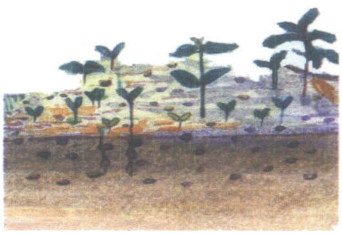
This gap is surrounded by mature seed-bearing rainforest trees that provide a dense seed rain.

Nearby forest provides habitat for seed-dispersing animals.

Sprouting tree stumps provide a source of rapid regeneration.

Naturally established tree seedlings and saplings are plentiful.

This area has only recently been deforested and was not subsequently cultivated. Therefore, viable seeds from the original forest remain in the soil seed bank.



Tree planting is not always essential for forest restoration. This deforested gap, amidst rainforest in southern Thailand, is small. Seeds are easily dispered into its centre. If sufficient numbers of tree species are regenerating from seeds, seedlings, saplings or tree stumps, there is no need to plant trees. However, if tree species richness is low, then enrichment planting with framework species is recommended (Part 5).

HELPING FORESTS TO HELP THEMSELVES – ACCELERATED NATURAL REGENERATION

"Knowing trees, I understand the meaning of patience. Knowing grass, I can appreciate persistence." - Anon

Part 3 identified the factors that hinder natural forest recovery in large deforested areas. The next logical step is to design practical techniques to overcome those limitations. In any particular location, several techniques are usually combined, to counteract each of the limiting factors that may be operating. Collectively, such techniques are termed "accelerated (or assisted) natural regeneration" or ANR for short.

SECTION 1 – WHAT IS ANR?

ANR covers any set of activities that enhance the natural processes of forest regeneration. These include promoting the natural establishment and subsequent growth of indigenous forest trees, whilst preventing any factors that might harm them *e.g.* competition from weeds, browsing by cattle, fire *etc.*

Because ANR relies on existing natural processes, it requires less labour input than tree planting and is therefore a very cheap way to restore forest ecosystems. However, ANR and tree planting should not be regarded as two exclusive alternatives to forest restoration. More often than not, forest restoration depends on the clever combination of tree planting with ANR techniques. Under certain circumstances, ANR may be sufficient alone to restore forest ecosystems, but tree planting should always be implemented in combination with whatever ANR techniques may be appropriate.

Where is ANR appropriate?

ANR is appropriate wherever the natural processes of forest regeneration are, to some extent, already happening. For example, at least a few seed trees should exist nearby and seed-dispersing animals should remain common in the vicinity. Sites, which already support a high density of tree saplings or sprouting tree stumps, are particularly suited to ANR.

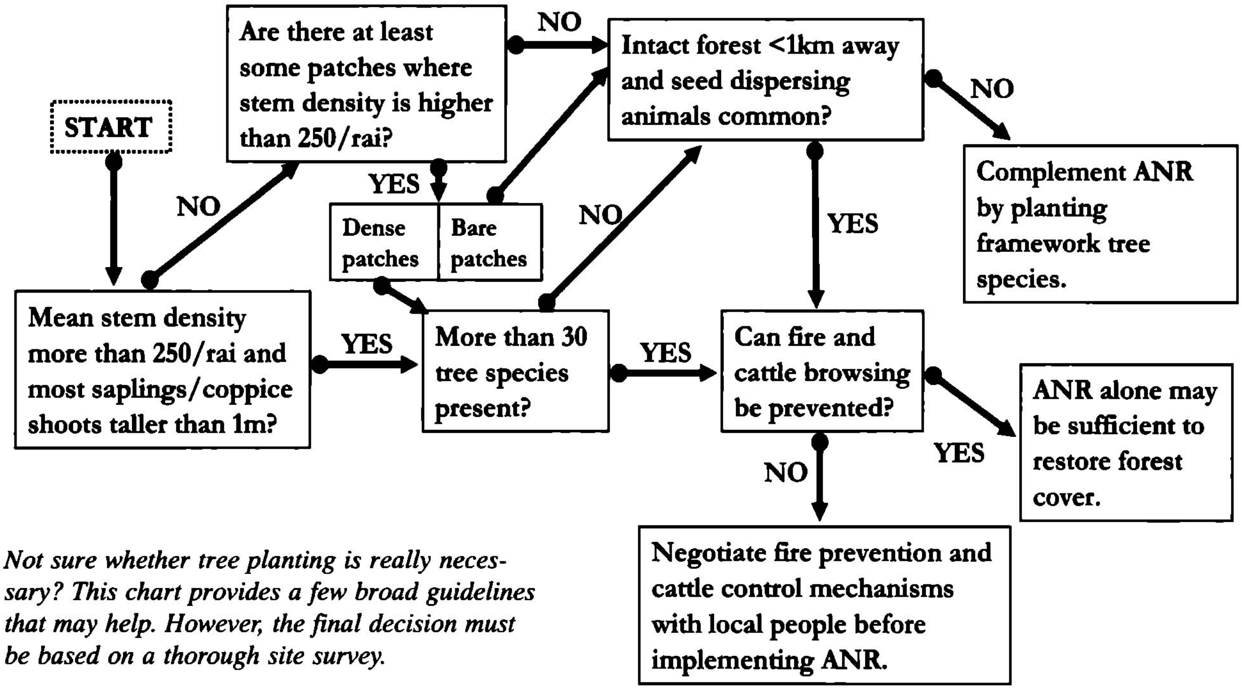
A detailed site assessment is necessary to decide if ANR might be sufficient, on its own, to restore forest and (if it is) to select the most appropriate techniques.

The site assessment should:-

i) determine the existing potential for natural forest regeneration and
ii) identify which factors might be limiting natural forest regeneration.

Direct observations of site conditions should be combined with interviews with local people to address the following questions:-

- What is the density of tree seedlings, saplings and tree stumps in the site? Are they evenly distributed or confined to a few parts of the site?
- How recently was the site deforested? Ask local people about the history of land use practices on the site.
- Does the site show signs of fire *e.g.* blackened tree stumps *etc.*? Ask local people how frequently fires occur in the area.
- Are there any signs that cattle use the site? Ask local people about cattle rearing practices in the area.
- How far away are the nearest sources of forest tree seeds?
- What is the status of seed-dispersing birds and mammals in surrounding areas?



Not sure whether tree planting is really necessary? This chart provides a few broad guidelines that may help. However, the final decision must be based on a thorough site survey.

The density of naturally occurring tree saplings and stumps (number of stems per hectare) provides a good prediction of whether ANR, on its own, may be sufficient to restore forest on any particular site. However, it is also important to consider the sizes of the saplings and stumps. Tall saplings are more likely to survive than small ones. The chances of a sapling growing into a mature tree increases greatly once it overtops surrounding weeds. So, it is also useful to record whether saplings are taller or shorter than the weed canopy.

Randomly place circular sample plots across the site. Use a pole to mark the centre of each plot and a 5-m-long piece of string as the radius. Count, identify and measure all stumps and saplings taller than 1 m, closer than 5 m to the pole. Calculate density by dividing the total number of saplings/stumps counted by the total area surveyed.

As a rough guide; if the density of saplings + live stumps exceeds 250 stems per rai (1,562 per hectare), ANR alone may be sufficient to restore basic forest structure within 5 years, provided fire, cattle and other limiting factors are controlled. Where density of saplings + live stumps is lower, ANR alone is unlikely to be successful, unless the site is very close to intact forest and seed-dispersing animals are common. If these conditions are not met, ANR should be combined with tree planting.

The intensity of tree planting required may vary within sites, since the distribution of natural saplings and tree stumps is often patchy or clumped. For those parts of the site undergoing vigorous regeneration, such as forest edges or around remnant, fruiting trees, tree planting would be a waste of resources. In the centers of large deforested areas, where tree seedling recruitment may be limited by distances from seed sources, the need to augment ANR with tree planting will be greater.

What are the limitations of ANR?

ANR acts mostly on trees that are already established in deforested areas. Unfortunately, most of the tree species that are capable of colonizing such areas are light-demanding pioneers (see Part 3, Sections 1 & 8), with seeds dispersed by the wind or small birds. They represent only a small fraction of the tree species richness of climax forest. Therefore, whilst ANR, might be sufficient to restore tree cover and to some extent forest structure, full recovery of biodiversity may require additional measures. Where large seed-dispersing animal species have become extirpated, planting large-seeded climax forest tree species may be the only way to convert secondary forest, created by ANR, back into primary forest.

Section 2 – Taking Care of What's Already There

The most thoroughly tested and widely practiced ANR techniques are those, which increase survival and growth of the woody plants that are already established on a site. Various methods are used to manipulate the environmental conditions around the seedlings and saplings of woody plants, as well as sprouting tree stumps, to accelerate their growth and to protect them from harm.

Can tree stumps be encouraged to sprout?

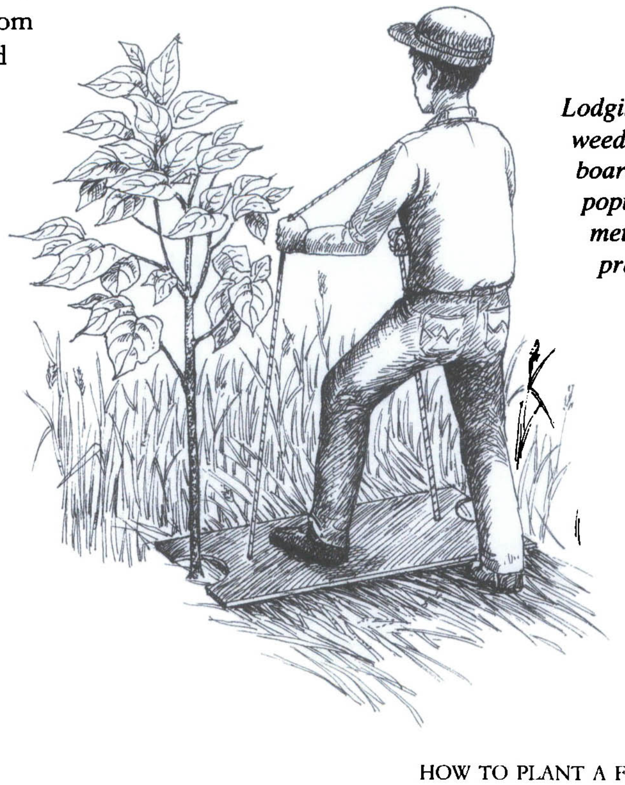
Sprouting tree stumps provide the most rapid means of re-establishing forest cover in seasonal tropical forests. Consequently, where they exist, they should be the focus of initial ANR efforts. Coppicing shoots can grow much faster than tree seedlings, since they can draw on large food reserves through the stumps' existing root systems. They are less susceptible to drought than seedlings, and they are thus less affected by weed competition. Held above the weed canopy, coppicing shoots are less likely to burn during a fire, but even if they do, they can recover rapidly.

However, almost no practical techniques have been tested to enhance the role of tree stumps in ANR, besides general recommendations that they should be protected from chopping, burning or browsing. Would application of plant hormones encourage sprouting? Could chemicals be used to prevent fungi or termites attacking tree stumps? Would laying mulch or applying fertilizer around tree stumps have the same beneficial effect as they do on tree seedlings? If many coppice shoots are growing from a single tree stump, would trimming back the weaker, smaller shoots enhance growth of the taller, stronger ones? These questions would make interesting topics for future research. Practitioners of ANR are encouraged to experiment.

How can competition with weeds be reduced?

Weeding, to reduce competition with herbs and grasses, is just as beneficial for naturally established trees as it is for planted ones. The smaller the tree seedlings or saplings, the more they benefit from weeding, especially during the rainy season. In the dry season, a weed canopy may help to protect small tree seedlings from desiccation (Hardwick, 2000), but this potentially beneficial effect must be weighed against the fire risk posed by the dried vegetation. Weeding around tree stumps is unlikely to be very beneficial, since tree stumps already have deep root systems that extend well below those of herbaceous weeds.

Before weeding, tree seedlings or saplings should be clearly marked with brightly coloured tape or poles, to make them more visible. This prevents accidentally trampling or cutting them during weeding. Weeding should first be concentrated around the marked trees, before clearing weeds from the rest of the site. Around small seedlings, it is better to hand-pull weeds than to use tools, since digging can damage the seedlings' delicate root systems. Suitable weeding techniques are described in detail in Part 7, Section 4.



Lodging, or flattening weeds with wooden boards has become a popular weed control method amongst ANR practitioners.

One weeding method that seems particularly suited to ANR is "lodging", *i.e.* flattening weeds with a board, rather than cutting them or digging them out. This does not kill the weeds immediately but each time the weeds grow back, they use up food reserves stored in their root systems. If the weeds are flattened often enough, food reserves are eventually exhausted and the plants die. Lodging weeds does not disturb the soil surface and, by shading the soil, the flattened weeds suppress germination of light-dependent weed seeds. This technique is particularly effective against grasses and bracken fern.

Use a wide plank of hard but lightweight wood (about 5 x 25 x 130 cm). Carve out semicircles at both ends of the plank so that it can be used to flatten weeds growing close to tree saplings. Attach a piece of sturdy rope and a shoulder pad to both ends of the plank, making a loop, long enough to pass over your shoulders. Lift the plank onto the weed canopy and step on it with full body weight. Repeat this action, moving forward in short steps (for more information please log on to http://www.fs.fed.us/psw/publications/documents/other/3.pdf). The method has been used to great effect in the Philippines to clear *Imperata* grass and accelerate forest regeneration on abandoned slash and burn sites there (Sajise, 1972).

Can mycorrhizae increase tree growth?

The dependence of tropical trees on symbiotic relationships with mycorrhizal fungi has already been explained in Part 3, Section 6. The prevalence of such relationships raises the question: could inoculating naturally establishing trees with mycorrhizal fungi improve their performance?

Recently, commercial preparations of mycorrhizal spores have become available. Usually such products contain a mixture of spores of several ubiquitous fungus species, adsorbed onto an inert substrate. However, as far as we are aware, the use of such products to improve performance of naturally establishing tree seedlings in ANR sites has never been tested. This is clearly another topic worthy of further research.

Should cattle be removed?

Ultimately, the decision to reduce the number of cattle or to remove them altogether depends on careful consideration of their economic value to the community, balanced against their effects on the regenerating trees.

In Nepal, villagers do not allow cattle to roam freely in their community forests. To protect the trees, villagers keep their cattle at home. They cut forage from the forests and bring it to their villages to feed their cattle. Not only does this feed the cattle without damaging the trees, but it also encourages effective weeding of forest plots. On the other hand, in Central America, cattle are used as an important tool in the early stages of forest restoration. They are regarded as "living lawn mowers", releasing young trees from competition with grasses and providing a vital seed dispersal service for some of the dominant forest tree species. Using cattle to control herbaceous vegetation also reduces fire risk.

How can fire be prevented?

As already explained in Part 3, Section 7, fire is the most serious hindrance to forest regeneration in the seasonally dry tropics. Where the fire risk is considered to be significant, fire prevention is a vital activity for ANR. Firebreaks around ANR sites must be cut at the beginning of the hot, dry season and a fire warning and suppression system must be maintained until the rainy season begins. These techniques are described in detail in Part 7.

What other techniques can be used to encourage tree growth?

The same methods of mulching and fertilizer application, described in Part 7 for planted trees can be used to enhance growth and survival of naturally established trees. Small seedlings or saplings are more likely to respond positively to such treatments than large trees. It is probably a waste of effort and expense to apply such treatments to older saplings and tree stumps, since they would already have developed deep root systems.

SECTION 3 – INCREASING THE SEED RAIN

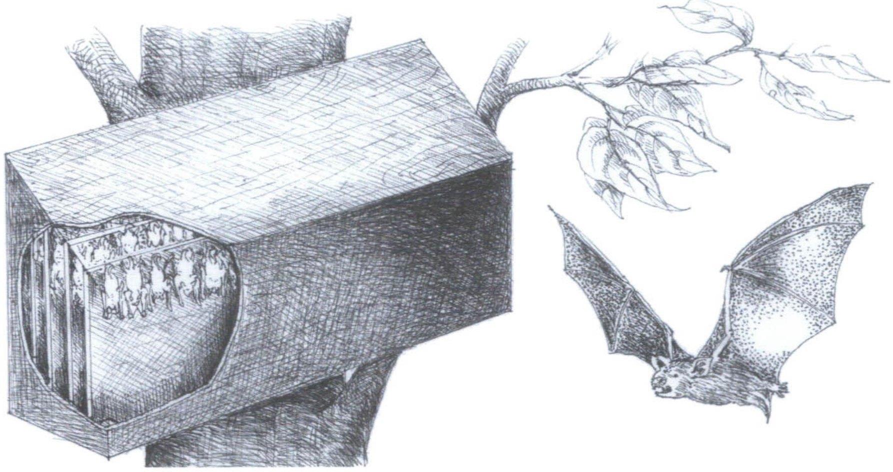
After severe and prolonged disturbance, remnant tree stumps, seedlings and the soil seed bank will be sparse or absent, so the potential for natural regeneration will depend critically on the seed rain.

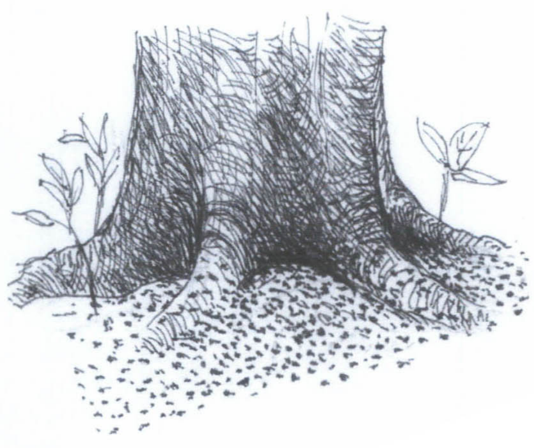
Can seed-dispersers be attracted to ANR sites?

Yes. The seed rain can be dramatically increased by adding very simple structures to ANR sites that attract the most common seed-dispersing animals *i.e.* birds (particularly bulbuls) and fruit bats.

Research in FORRU's experimental plots has shown that simple artificial bird perches, made from bamboo, placed randomly across sites, can significantly increase the seed rain (see Box 4.1). Moving such perches around, from time to time, could help to distribute seeds over wider areas. Adding bait to the perches may increase their attractiveness (but is labour intensive) and clearing weeds beneath them increases survival of germinating tree seedlings. Bird nesting boxes may have a similar effect.

Roosting boxes may attract small fruit bats into ANR plots. Such bats drop seeds in flight, creating a widespread seed rain around the boxes, but the potential of bat boxes to accelerate forest regeneration has never been tested.





Seedlings growing from seeds dropped by bats

Provision of roosting boxes might attract seed-dispersing fruit bats into ANR sites. The boxes can be hung from remnant trees or mounted on tall poles. Bats have very particular requirements so it is important that boxes are made from rough timber and that the entrance to the box matches the body size of the target bat species. Detailed instructions for construction of bat boxes are provided at http://www.dnr.state.md.us/wildlife/batboxes.html. Unlike bird perches, the effects of bat boxes on forest regeneration in the tropics have never been tested.

Structurally diverse vegetation, especially fruiting shrubs or remnant trees, act as natural attractants to seed-dispersing animals. So, protecting such vegetation will greatly help to increase the seed rain.

In seasonally dry climates, water is a strong attraction to wildlife, so digging artificial ponds might also attract potential seed dispersers.

Can large, seed-dispersing animals be brought back?

As already explained in Part 3 Section 3, large seed-dispersing animals (*e.g.* elephants, rhinos and wild cattle) have been extirpated over much of their former ranges or reduced to populations too small to play a significant role in seed dispersal. So might it be possible to bring them back? After all, human beings must be paid to plant trees, whereas elephants not only plant tree seeds, but provide them with a generous dose of fertilizer, for free!

Unfortunately, re-introduction of large seed-dispersing mammals is a difficult and expensive process. It is only worthwhile where the problem, which caused the species to become extirpated in the first place, has been solved. This usually means persuading local people not to hunt re-introduced animals.

Re-introducing captive animals back into their natural habitats is particularly difficult because captive animals often lose the skills needed to survive in the wild. A lengthy rehabilitation process is usually necessary. However, even translocating wild animals, from conservation areas where they are common, to those where they have become extirpated, is not easy. The risk of death or injury during capture is high and the source population may be seriously disturbed or depleted. Veterinary care, maintaining genetic diversity within small populations, monitoring animals after release and, most crucial, preventing hunting, are all vital components of any animal re-introduction programme.

In addition to the technical issues, local people may object to the return of large animals, which might damage crops, compete with domestic animals or threaten human life.

However, such obstacles are not insurmountable. For example in northern Thailand, domestic elephants have been successfully returned to the wild. So, despite the difficulties, re-introduction programmes are worth careful consideration. For further information, please refer to the guidelines issued by the Species Survival Commission of the International Union for the Conservation of Nature (http://iucn.org/themes/ssc/pubs/policy/reinte.html).

Can people be seed dispersers?

Yes. One method of forest restoration is to collect seeds from nearby forest trees and sow them in deforested sites. This is called "direct seeding". The technique can rapidly increase tree density as well as tree species richness, but it has several drawbacks. The hot, dry conditions, of most deforested sites can rapidly desiccate seeds on the soil surface. In addition, seed predators, such as rodents and ants, (see Part 3, Section 4) are particularly common in deforested sites and can cause complete loss of some tree seed species, within a few days after sowing.

Direct seeding

First, clear weeds from seeding spots.

Next, make small holes and half fill them with forest soil.

Burying seeds can substantially reduce both desiccation and predation, but it also increases the labour input required. Selecting tree species with seed characteristics that make them resistant to predation (*e.g.* small size, tough seed coat, *etc.* see Part 3, Section 4) can increase the success of direct seeding. Treating seeds with chemical repellents is also worth exploring, but further research is needed to identify compounds that deter seed predators without harming the seeds. Since prolonged dormancy increases the chances that seed predators will find seeds, treating seeds to break dormancy (*e.g.* soaking, scarification *etc.*), before direct seeding, might shorten that vulnerable period, during which predation could occur. However, sometimes such treatments can increase the risk of desiccation or make seeds more attractive to ants by exposing the cotyledons.

As with nearly all ANR techniques, experiments must be carried out to determine the most successful techniques to use in any particular site. Naturally, any animals, which prey on rodents (*e.g.* birds of prey, wild cats *etc.*), should be regarded as valuable assets on ANR sites. Preventing the hunting of such animals can help control rodent populations and reduce seed predation.

If it is decided to include direct seeding in an ANR programme, try the procedures in the diagrams below. At the beginning of the rainy season, collect seeds from fruiting forest trees, near to the ANR site. Dig out weeds in "seeding spots", approximately 30 cm across, spaced about 1.5-2 m apart (the spacing can be wider where saplings or tree stumps are common).

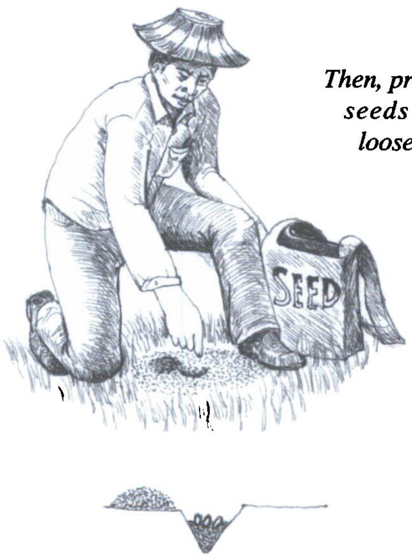
Dig a small hole in the soil and loosely fill it with forest soil (dug up from where the seeds were collected). This ensures that beneficial symbiotic micro-organisms (*e.g.* mycorrhizal fungi *etc.*) are present when the seed germinates. Finally, press several seeds into each hole, to a depth of about twice the diameter of the seed and cover with more forest soil.

What if ANR doesn't work?

ANR is a very young science, as is apparent from the many "topics requiring further research" identified in this part. Provided ANR techniques are applied to a suitable site, they are unlikely to be a complete failure, but they might not yield desired results quickly enough, especially biodiversity recovery.

Another approach is to use a "nurse crop" of trees to re-establish canopy cover, whilst also implementing ANR techniques. This approach is called "foster ecosystem" or "plantations as catalysts". Almost any tree crop will encourage the processes that accelerate forest regeneration, by ameliorating the micro-climate and attracting seed-dispersing birds. Even an exotic tree species can be used, especially where economic benefits are required. The nurse crop is gradually thinned, to yield an economic return, as the plantation becomes colonized by forest trees (Parrotta *et al.* 1997).

However, planting a single tree species needlessly delays biodiversity recovery. Hence the "framework species method" is explained and recommended in the next part.



Then, press several seeds into the loose soil.

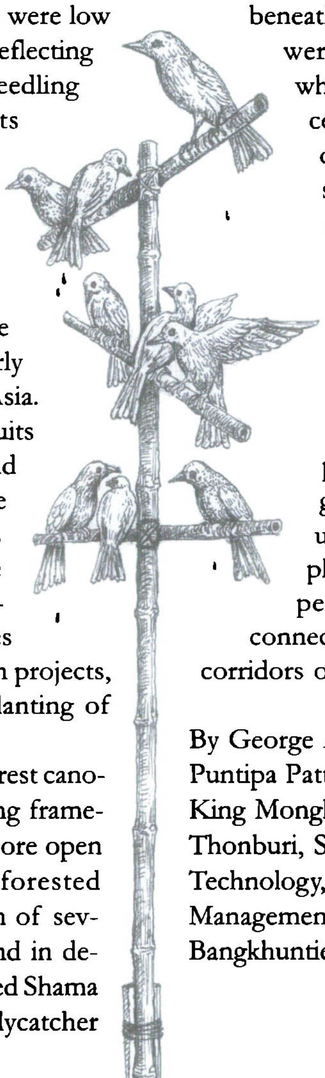
Finally cover the seeds with more forest soil.

Box 4.1 - The Role of Birds in Forest Regeneration

Dr. George Gale and his team from King Mongkut's University of Technology Thonburi, placed artificial bird perches, made of bamboo, in deforested areas in the highlands of northern Thailand. Some plots were being planted with framework tree species, whilst others were undergoing natural regeneration. They observed which bird species used the perches; counted seeds dropped by the birds beneath the perches and monitored seedlings that subsequently established (see Scott et al, 2000).

"Artificial perches in deforested areas attracted many seed-dispersing birds. Although direct observations of birds on the perches were infrequent, birds clearly used the perches often enough to significantly increase seed input. Below the perches, both the seed rain and seed germination significantly increased, compared with adjacent control plots with no perches. Seedling survival below the perches was also higher than in the control plots, although seedling numbers were low in both perch plots and controls, reflecting the naturally low rate of tree seedling survival in the wild. Two plants commonly found in disturbed areas, the treelet *Melastoma malabathricum* and the tree, *Trema orientalis*, accounted for more than 50% of new seedlings found growing beneath the perches. These are important early successional species throughout Asia. In particular, *M. malabathricum* fruits are frequently eaten by birds and other wildlife. However, if the surrounding vegetation grows above the perches, they become less attractive to birds; an important consideration, if bird perches are to be used in forest restoration projects, especially those involving the planting of fast-growing trees.

In forest restoration plots, forest canopy closure, 2-3 years after planting framework tree species, resulted in a more open understorey, more typical of forested areas. This encouraged the return of several bird species not usually found in degraded areas, such as White-rumped Shama (*Lonchura striata*) and Hill Blue Flycatcher (*Cyornis banyumas*).



Bird perches are very inexpensive, compared with producing trees in nurseries and planting them. In addition, minimal labour is required to erect and maintain the perches, compared with the very high labour inputs needed for tree planting. However, tree planting does appear to be more effective at restoring biodiversity-rich forest in highly disturbed sites compared with using perches alone.

Furthermore, natural tree recruitment beneath perches was higher at sites, which were only moderately disturbed and which had at least some nearby tree cover. Success with perches seems to depend on the proximity of early successional tree species. Few late succession tree species recruited beneath perches.

Thus, we recommend that artificial perches are used in conjunction with restoration tree planting, particularly during the first two to three years after planting, before the planted trees grow tall. Perches may be particularly effective along the edges of planted sites. Furthermore, rows of perches could be erected to interconnect planted areas with "bird-created" corridors of early successional vegetation."

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Attracting Animals that Help to Restore Forest Biodiversity

Cynopterus sphinx - *a medium-sized bat. Flying long distances during nights spent feeding on fruit, this bat disperses seeds over long distances and often drops them into deforested areas. Is it possible to attract bats like this into ANR plots?*

Where they remain extant, wild cattle (such as the Gaur pictured above) and other large seed-dispersing animals can be attracted into ANR plots by making artificial water holes or salt licks.

P. Round

At home in both forest and deforested sites, five species of Bulbul are among the most important dispersers of seeds into ANR plots in northern Thailand (Part 3, Section 3); including the Black-crested Bulbul (above), Red-whiskered, Sooty-headed, Black-headed and Flavescent.

A. J. Pierce

Feeding on both insects and fruits in forest and open habitats, the White-browed Scimitar Babbler is attracted to perches in ANR sites.

A. J. Pierce

A. J. Pierce

Once canopy closure is achieved, the Hill Blue Flycatcher (far left) and White-rumped Sharma (left) are among the first climax forest bird species, to colonize newly restored forest plots.

Increase the animal-dispersed seed rain by erecting bird perches or bat boxes or by making artificial ponds or salt licks to attract seed-dispersing animals into ANR sites. Strict precautions, to completely prevent hunting of such animals, are essential for successful ANR.

The photos above were taken as part of a properly supervised scientific study, by trained researchers. Birds were subsequently released.

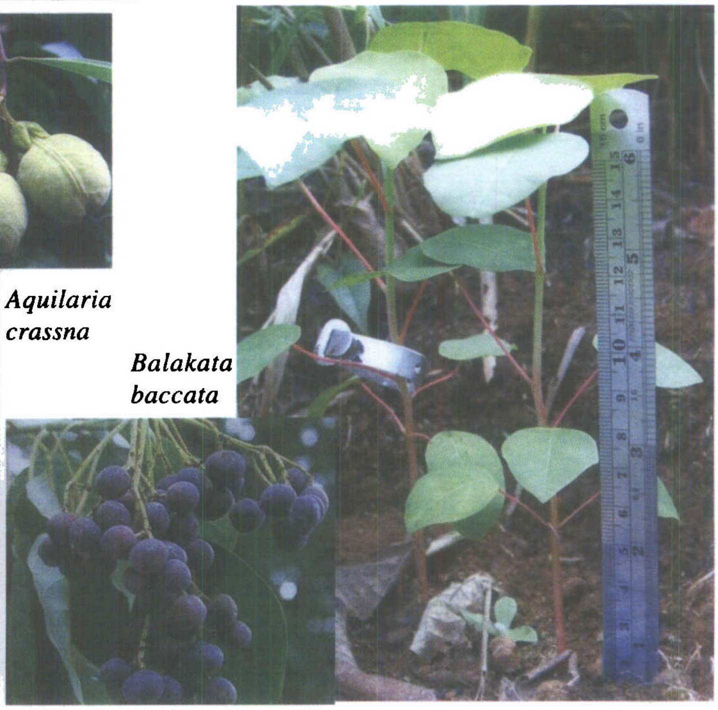
Box 4.2 - Testing the Effectiveness of Direct Seeding

Tunjai (2005) investigated which tree species may be suitable for direct seeding in both deciduous and evergreen forest types in northern Thailand. She collected seeds from fruiting trees and sowed half of them in a nursery under standard conditions and the rest directly into deforested sites at the start of the rainy season, using the methods previously described in Section 3. For several species, germination percent and early seedling survival and growth were higher in the field than in the nursery. After one year, nursery-raised saplings were planted next to direct seeded saplings in the field. Subsequent monitoring confirmed continued high relative performance of direct seeded saplings of several species. Direct seeding is cheaper than planting nursery-grown trees. So, future forest restoration systems may well incorporate both direct seeding, for those tree species that respond well to the techique, and conventional tree planting, for those that do not. Based on Tunjai's experiments, direct seeding is recommended for *Afzelia xylocarpa, Schleichera oleosa* and *Trewia nudiflora* in deciduous forest types, and for *Aquilaria crassna, Balakata baccata, Eugenia fruticosa, Gmelina arborea, Melia toosendan, Prunus cerasoides, Sarcosperma arboreum* and *Spondias axillaris* in evergreen forest sites.

Afzelia xylocarpa

Trewia nudiflora

Aquilaria crassna



Balakata baccata

PART 5

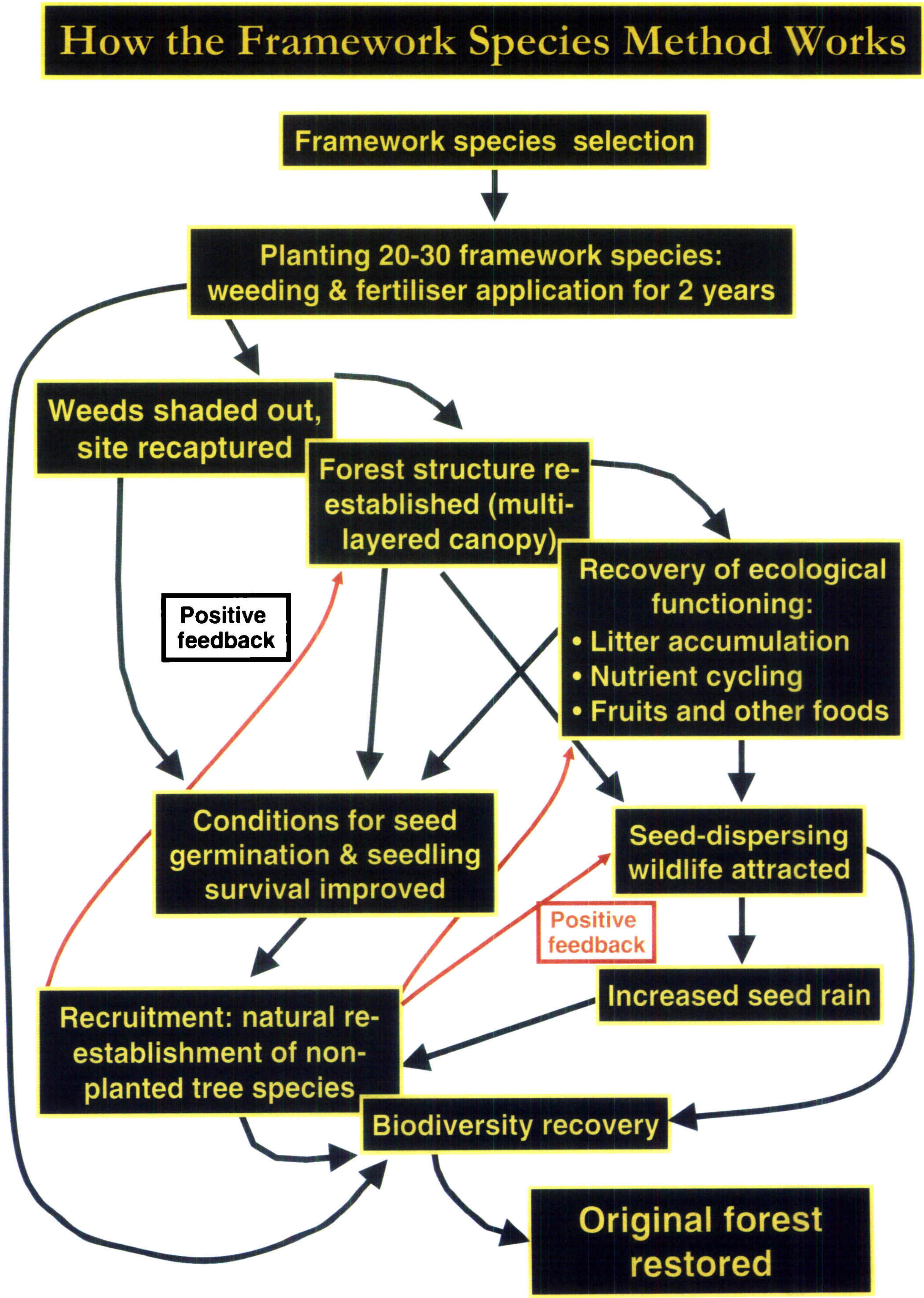
The Framework Species Method of Forest Restoration

* *

Defining the Concept
Selecting Framework Species
Testing Framework Species

"The "framework species" method, developed in northern Queensland (Goosem and Tucker, 1995) uses suites of local tree species that promote more rapid natural succession. It has greatest potential where substantial forest tracts and remnants still exist"

- four of the world's leading forest restorationists: David Lamb, John Parrotta, Rod Keenan & Nigel Tucker, 1997


How the Framework Species Method Works
Framework species selection
Planting 20-30 framework species: weeding & fertiliser application for 2 years
Weeds shaded out, site recaptured
Forest structure re-established (multi-layered canopy)
Recovery of ecological functioning:
• Litter accumulation
• Nutrient cycling
• Fruits and other foods
Positive feedback
Conditions for seed germination & seedling survival improved
Seed-dispersing wildlife attracted
Positive feedback
Increased seed rain
Recruitment: natural re-establishment of non-planted tree species
Biodiversity recovery
Original forest restored

The Framework Species Method of Forest Restoration

"The destruction of rainforest has sparked an unprecedented response in many people to both save what remains and if possible rebuild what we can."
- Steve Goosem and Nigel I. J. Tucker, "Repairing the Rainforest", 1995.

Section 1 – Defining the Concept

What is framework forestry?

Even though forest restoration is a young science, several different approaches have begun to emerge. They vary in intensity, from ANR with no tree planting (Part 4) to the planting of all the tree species that formerly comprised the original climax forest (*e.g.* the maximum diversity method of Goosem and Tucker (1995) or the Miyawaki method from Japan (Miyawaki, 1993)). The framework species method is a compromise between these two approaches. It is more effective at restoring biodiversity than the former, whilst requiring fewer inputs than the latter.

It combines the planting of a moderate number of key tree species, selected for their potential to accelerate biodiversity recovery, combined with various ANR techniques (Part 4) to enhance natural regeneration, creating a self-sustaining forest ecosystem from a single planting event. Originally conceived in northern Queensland to repair damaged tropical rain forest (Goosem and Tucker, 1995), the framework species method has been successfuly modified to restore seasonally dry tropical forests to deforested sites in northern Thailand's conservation areas.

What are framework tree species?

Framework trees are **indigenous**, non-domesticated, forest tree species, which, when planted on deforested land, help to re-establish the natural mechanisms of forest regeneration and accelerate biodiversity recovery.

How does it work?

The framework species method involves planting 20-30 carefully selected tree species and caring for them for two or more years (*e.g.* weeding, applying fertilizer *etc.*) The planted trees "re-capture" the site, by shading out herbaceous weeds. They also re-establish forest structure, by developing a multilayered canopy. Furthermore, they restore ecosystem processes, such as nutrient cycles, and improve conditions for seed germination and seedling establishment of additional (non-planted) tree species (termed "recruits"), by creating a cooler, more humid microclimate on the forest floor. Moist, nutrient-rich leaf litter, free of weed competition, creates the perfect conditions for germination of incoming tree seeds and survival of tree seedlings.

Biodiversity recovery relies on birds, bats and other small mammals being attracted to the planted trees. The 20-30 tree species planted represent only a fraction of the total number of tree species that grow in tropical forest ecosystems. To restore the forest's original tree species composition, wildlife must be employed as seed-dispersers. Once planted trees have created conditions conducive to tree seedling recruitment, they must produce resources (*e.g.* nectar-rich flowers, fruits or bird nest sites *etc.*), which attract seed-dispersing animals. These animals transport seeds of many additional tree species from nearby surviving forest into the planted sites. It is this next generation of naturally established trees, germinating from the seeds brought in by animals, which ultimately restores the forest to its original condition.

What are the characteristics of framework tree species?

The essential ecological characteristics of framework tree species are therefore:-

- high survival when planted out in deforested sites;
- rapid growth;
- dense, spreading crowns that shade out herbaceous weeds and
- flowering and fruiting, or provision of other resources, at a young age, to attract seed-dispersing wildlife.

In addition, framework species must be easy to propagate in nurseries, using simple techniques. Trees cannot be planted if they cannot be grown. Therefore, desirable nursery characteristics of framework tree species include reliable seed availability; rapid and synchronous seed germination and, most importantly, production of vigorous seedlings of a plantable size in less than 1 year.

In the seasonally dry tropics, where wild fires in the dry season are an annual hazard, an additional essential characteristic of framework species is resilience after burning. When fire prevention measures fail, the success of forest restoration plantings can depend on the ability of the planted trees to re-sprout from their rootstock after fire has burnt their above-ground parts (*i.e.* coppicing).

Macaranga denticulata *has a dense tree crown, which rapidly shades out weeds; a desirable characteristic of framework tree species.*

Are there any other tree characteristics important for biodiversity conservation?

Rare or endangered tree species require special consideration. Including such species in forest restoration plantings, can help prevent their extinction, even if they may lack some framework characteristics. A database of the world's endangered tree species is maintained by the World Conservation Monitoring Centre at: - www.unep-wcmc.org/cgi-bin/SaCGI.cgi/trees.exe?FNC=database_Aindex_html.

In addition, where large seed-dispersing animals (*e.g.* elephants, wild cattle, rhinos *etc.*) have disappeared, planting tree species with **large, animal-dispersed seeds** (often climax forest species) has obvious benefits.

Are framework trees pioneer or climax species?

Mixtures of framework tree species planted should include both pioneer and climax species (see Part 3). Goosem and Tucker (1995) recommend that at least 30% of trees planted should be pioneers. By planting both pioneer and climax trees in a single step, forest succession can be short-circuited. Many climax forest tree species perform well in the open, sunny conditions of deforested areas, but they fail to colonize such areas due to lack of seed dispersal. Many climax tree species have large, animal-dispersed seeds. The decline of large mammals, over wide areas now prevents dispersal of large-seeded, climax trees into deforested sites. By including some climax forest tree species amongst those planted, it is possible to overcome this limitation and accelerate recovery of climax forest.

Fast-growing, pioneer trees rapidly close canopy and shade out weeds, whilst slower growing climax species form an understorey beneath the pioneer tree crowns, adding structural diversity to the forest and increasing the variety of wildlife resources available. Pioneer trees begin dying 15-20 years after planting. However, by this time, a rising understorey of climax forest trees is ready to replace them, along with a dense layer of naturally established trees, derived from seeds brought in by wildlife.

What kind of animal species must planted framework trees attract?

Any trees can provide perches that birds may use for short visits, but trees that provide food or nesting sites can attract seed-dispersing animals for longer periods, during which the animals may deposit seeds that begin the process of restoring the forest's original tree species composition. Therefore, planted framework trees act as "bait" for seed-dispersing animals.

As already explained in Part 3, dispersal of seeds between intact forest and planted plots is carried out by relatively few, common, fruit-eating, animal species that are equally at home in forest and in deforested areas. These include small to medium sized, birds, particularly bulbuls, fruit bats (*e.g. Cynopterus* spp) and a few other medium-sized mammals, including civets, Common Wild Pig, Common Barking Deer, Hog Badger *etc.*

Tree species that are most likely to attract such animals produce small to medium-sized fruits within 3 years after planting (*e.g.* in northern Thailand: *Callicarpa arborea, Castanopsis tribuloides, Eugenia grata, Ficus abellii, F. hispida, F. semicordata, F. subincisa, Glochidion kerrii, Heynea trijuga, Macaranga denticulata, Machilus kurzii, Prunus cerasoides* and *Rhus rhetsoides*) or flowers producing copious quantities of nectar (*e.g. Erythrina subumbrans*).

Tree species used by birds as nesting sites, within 5 years after planting include *Alseodaphne andersonii, Balakata baccata, Bischofia javanica, Cinnamomum iners, Duabanga grandiflora, Erythrina subumbrans, Eugenia albiflora, Ficus glaberima, F. semicordata, F. subincisa, Helicia nilagirica, Hovenia dulcis, Phoebe lanceolata, Prunus cerasoides, Pterospermum grandiflorum, Quercus semiserrata, Rhus rhetsoides* and *Spondias axillaris.*

Increases in insects in planted plots might also attract seed-dispersing birds and mammals with mixed diets, but little is known of how planted trees affect insect populations. More research to discover which insects are associated with each framework tree species would be beneficial.

The ability of planted trees to attract wildlife is one of the least known aspects of the framework species method. More research on the ecology and diet of seed-dispersers would enable better selection of framework tree species that are most likely to attract them.

What are the essential design features of a framework forest?

Between 20 and 30 framework tree species are planted on any particular site. The trees are randomly positioned across the site, averaging about 1.8 m between adjacent trees (about 494 trees per rai or 3,086 per hectare). This planting density can be reduced, if some naturally established tree seedlings are already present. Protecting and nurturing naturally established woody plants, during site preparation and tree planting activities, is an essential feature of the framework species approach.

What management is required?

For at least 2 years after planting, frequent weeding is essential, to prevent herbaceous weeds competing with the planted trees. Fertilizer application accelerates tree growth, resulting in rapid canopy closure, which shades out the weeds. In seasonally dry climates, an effective fire prevention program is also essential. Naturally established trees are nurtured and protected from fire in the same way as the planted trees. Preventing hunting is also necessary to conserve populations of seed-dispersing wildlife. Plantation design and management are discussed in detail in Part 7.

Does the framework species method have limitations?

For recovery of tree species richness, the framework species method depends on remnant natural forest existing nearby to provide a diverse seed source and habitat for populations of seed-dispersing animals. FORRU's work has shown that in degraded upland evergreen forest sites in northern Thailand, civets and other animals may disperse seeds of some forest tree species up to 10 km. So the technique can potentially work well within 10 km of forest patches. Scattered trees can also provide a seed source for recovery of tree species richness. If seed sources or seed dispersers are absent from the landscape, recovery of tree species richness may be slow. If planting framework tree species fails to stimulate biodiversity recovery within 4-5 years, subsequent enrichment planting with more tree species may be necessary.

SECTION 2 – SELECTING FRAMEWORK TREE SPECIES

Are there published lists of framework tree species?

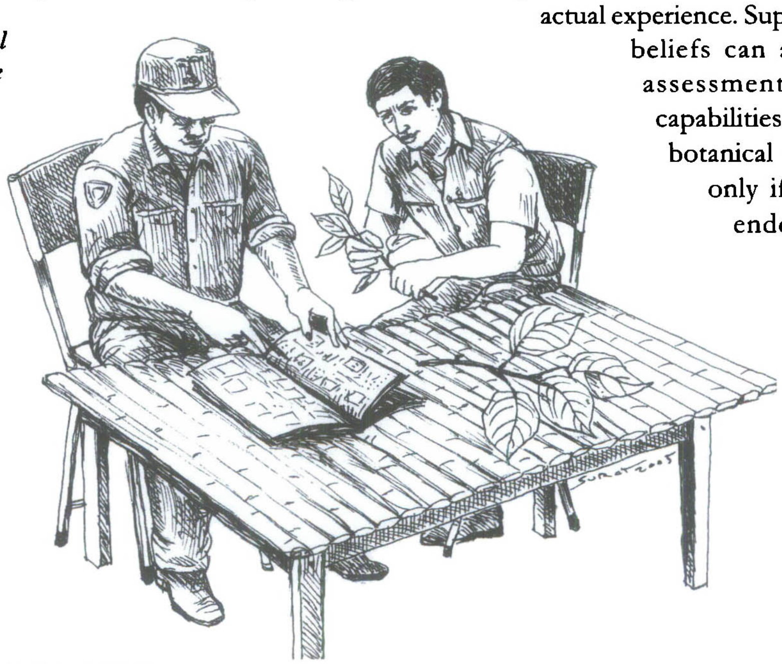
No lists of framework species have been published, except for Queensland's tropical rainforests in Australia (Goosem and Tucker, 1995) and the seasonally dry forests of northern Thailand (Part 9 of this manual). Elsewhere, framework tree species must be identified by assessing likely tree species for framework characteristics. The literature and indigenous knowledge can be used to identify candidate framework species, but their ability to perform as such must be confirmed by field trials.

How are candidate framework species selected?

Candidate framework species should be non-domestic and indigenous to the area being planted. Only tree species suited to the original forest type and elevation of the planting site should be selected for testing. This information can be found in botanical texts (*e.g.* for northern Thailand, Maxwell and Elliott (2001) and Gardner *et al.* (2000)). Although the literature usually describes flower or fruit characteristics likely to attract wildlife, it is important to complement such information by observing trees in the forest. Labelled trees should be observed monthly for fruits and seeds and the animals that disperse them. Such phenological studies generate information on when seeds may be collected and the attractiveness of each tree species to seed-dispersing animals. They also provide an opportunity to observe tree crown structure and consequently to judge how effectively tree species might shade out weeds

Published data on growth performance of the vast majority of tropical tree species are very scarce, but for Southeast Asian trees, some information is presented in the excellent handbooks on timber trees (Soerianegara and Lemmens, 1994; Lemmens *et al.*, 1995 and Sosef *et al.*, 1998, www.prosea.nl/prosea5.html#5(1)), published by PROSEA (Plant Resources of Southeast Asia). However, monitoring seedling growth in a nursery probably provides a better indication of potential performance. In most cases, species that perform well in nurseries are worth testing in the field.

Studies of the botanical knowledge of local people (ethnobotany) can provide insight into the potential of trees to act as framework species. When carrying out such studies, it is important to work with communities that have a long history of living close to forest and deforested areas, especially those that practice swidden (slash and burn) agriculture. Farmers from such communities usually know which tree species colonize fallow fields and grow fast. However, the results of such studies must be critically scrutinized. Local people sometimes provide information, which they think will please the researcher, rather than that based on actual experience. Superstition and traditional beliefs can also distort objective assessment of a tree species' capabilities. Consequently, ethnobotanical information is reliable only if it is provided independently, by members of several different communities, with different cultural backgrounds. To design effective ethnobotany surveys, please refer to Martin (1995).



Information from local people can contribute much to the selection of candidate framework tree species.

Table 5.1 Summary of information sources for initial selection of candidate framework tree species for assessment.

Framework Characteristics	Literature	Nursery Research	Field Observations	Ethnobotany
Indigenous, non-domesticated, suited to habitat/elevation	Often indicated in plant descriptions in botanical literature.		Survey tree species in nearest patch of intact forest.	Unreliable: villagers often fail to distinguish between native and exotic species.
High survival and growth	Published data sparse, but try PROSEA handbooks.	Assess seedling survival and growth in nurseries.	Assess survival and growth of trees establishing naturally in fallow fields.	Ask local people which tree species survive well and grow rapidly in fallow fields.
Dense broad crown, which shades out weeds	Few texts cover tree crown structure for individual tree species.		Observe crown structure of trees in the forest and fallow fields and weed cover beneath.	
Attractive to wildlife	Fleshy fruits or nectar-rich flowers described in taxonomic descriptions.		Observe fruit type and animals eating fruits or flowers in forest.	Villagers often know which tree species attract birds.
Resilient after fire			Survey tree survival in areas accidentally burnt.	Villagers often know which tree species recover after burning.
Easy to propagate		Germination experiments & seedling monitoring.		
Climax/large seeds	Often indicated in plant descriptions in botanical literature.		Observe fruits & seeds of trees in climax forest.	

SECTION 3 – TESTING FRAMEWORK TREE SPECIES

How are candidate framework species tested?

Once candidate tree species have been selected, field trials can be set up to determine to what extent their field performance conforms to "framework" criteria outlined in Section 1. Preparation for field trials may take a year or more, as sufficient numbers of seedlings (>50 per species) must be raised in a nursery, from seed collected from many parent trees (Part 6). Experimental plots should be planted with 20-30 candidate framework tree species (Part 7). Plots of at least one rai (40x40 m), replicated at least 3 times, are the minimum required, to show significant differences in survival and growth among the species tested (Part 7, Section 5). Identical silvicultural treatments must be applied to all replicate plots.

How soon can performance be assessed?

At the end of the second rainy season (*i.e.* approximately 1½ years) after planting, the monitoring methods described in Part 7, Section 5 can be used, to assess growth and survival of candidate framework tree species.

The greatest cause of mortality is drought stress during the first dry season after planting. By the end of the second rainy season, most trees have either established well or died. Therefore, survival and growth at that time provide a good indication of ultimate performance. In contrast, provision of wildlife resources by the planted trees and biodiversity recovery occur more slowly. Consequently, monitoring these framework characteristics must continue for at least 5 more years.

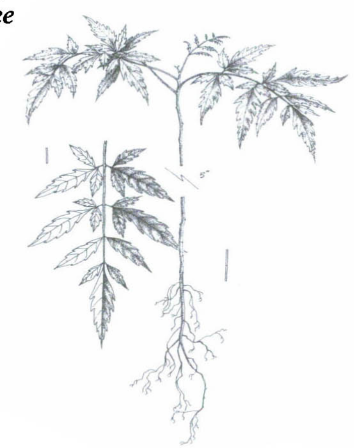
Table 5.2 Proposed minimum field performance standards for framework species at the end of the second rainy season after planting on evergreen forest sites in northern Thailand (Elliott *et al.*, 2003)

Measurement[1]	Excellent	Acceptable	Marginal	Reject
Survival (%)	>70	50-69	45-49	<45
Height (m)	>2.0	1.5-1.99	1.25-1.49	<1.25
Crown width (m)	>1.8	1.5-1.79	1.00-1.50	<1.0
Reduction in weed cover score	>1	0.5-1.00	0.40-0.49	<0.4
Survival after fire[2] (%)	>70	50-69	45-49	<45

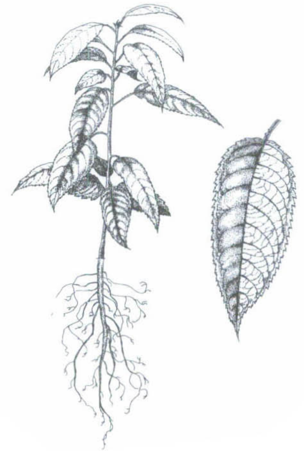
[1]For measurement techniques and definitions see Part 7 Section 5

[2]Measured when fire prevention fails and trees burn accidentally. **Do not deliberately burn plots.**

Saplings of some of the top-performing framework tree species, which FORRU has identified, using the screening process described here.



Melia toosendan Sieb. & Zucc.



Prunus cerasoides **D. Don**

Spondias axillaris **Roxb.**

Can performance standards be used to select framework tree species?

Flexibility is needed if performance standards are used to judge whether planted tree species qualify as framework species. Tree performance can be highly variable. Variability in climate from year to year can result in a species meeting the standards one year and failing to do so the next.

If growing trees from seed, suitable nursery standards by which to judge "ease of propagation" are: i) seed germination rates higher than 40%; ii) survival rates higher than 70% and especially iii) production of plantable saplings within a year after seed collection.

The field performance standards presented in Table 5.2 have been developed by FORRU to enable initial evaluation of potential framework tree species for restoring evergreen forest sites by about 18 months after planting.

Production of flowers or fruits or observations of birds' nests in the trees, within 4 years after planting, is a useful standard, by which to assess provision of wildlife resources.

Selecting framework species, requires a combination of quantitative measurements and subjective assessment. Very few tree species tested will exceed all the standards, but among any mixture of 20-30 species planted on any particular site, all framework characteristics should be collectively well represented.

For example, although fast growth is desirable, a few slow-growing species might be tolerated to diversify canopy structure and create understorey niches for wildlife. Likewise, a few species with narrow crowns might be acceptable in the planting mixture, provided they perform well in other respects.

Ficus subincisa *is excellent for attracting seed-dispersing birds, since it bears figs within a year after planting.*

Sapindus rarak *is a framework tree species with economic value. Its fruits are used to make soaps and shampoos.*

What if too few of the candidate framework species tested meet the standards?

If none or too few of the tree species tested meet the suggested standards, there are two options. Firstly, other, more promising candidate species may be selected for additional trials from amongst the local tree flora by re-evaluating the selection process.

Alternatively, the performance of those species that failed to meet standards in initial trials can be increased by various means. If species fail to meet nursery standards, propagation techniques can be modified to produce more vigorous planting stock (*e.g.* better media, fertilizer treatments *etc.*). In the field, silvicultural treatments can be intensified (*e.g.* more frequent weeding, mulching *etc.*) to improve growth and survival and accelerate canopy closure.

A ranking system can be used to select species with the highest relative performance from amongst those that fail initial field trails. Those species can then be prioritized for nursery and field experiments to develop techniques to improve performance. An example is provided in Table 5.3. Species ranked in the top 50% for all measurements (*i.e.* species A, B & C (rank scores all 4-6)) or those with the highest total rank scores could be recommended for further experiments.

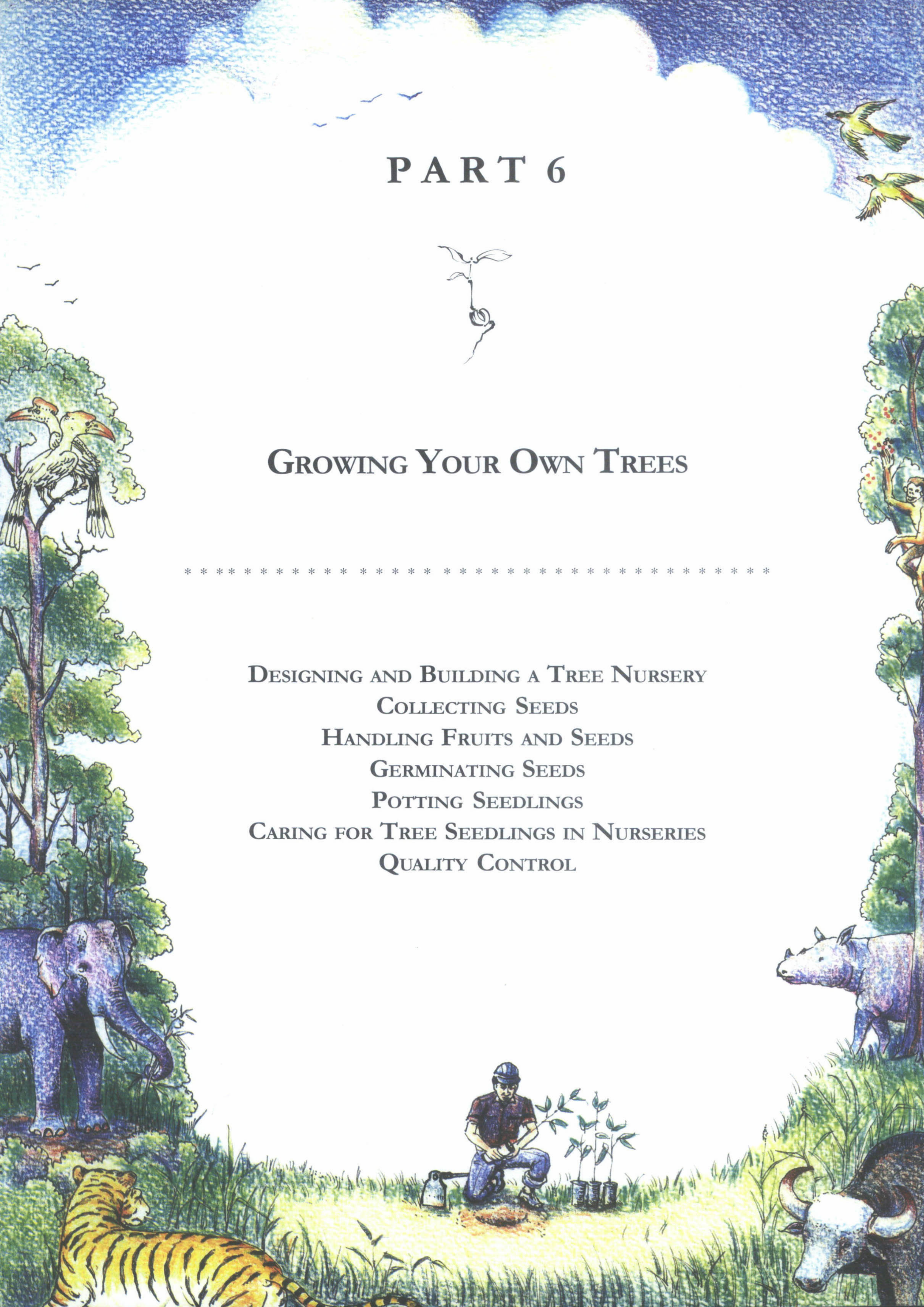
A variation of this technique is to apply different weights (or multipliers) to each framework characteristic, according to its relative importance. For example, survival is more important than seedling height, so the rank scores for survival could be multiplied by 1.5 or 2, before addition to the total rank score. Factors which affect the magnitude of the multiplier applied might include; harshness of planting site; proximity to intact forest; seed availability or quality of nursery operation *etc.*

What about the economic value of framework tree species?

Framework tree species are most suitable for promoting biodiversity conservation in protected areas, where forest exploitation is minimal. Therefore, their commercial value is secondary to their ecological value. However, even within conservation areas, use of the forest by local people is often an important consideration. In such circumstances, framework species, which also yield non-timber products, should be selected. Remember, **there is no such thing as a *non*-economic tree species.** Most framework tree species yield several useful products such as traditional medicines, edible fruits or foliage, fuel-wood, fodder for domestic animals *etc.* In addition, the value of environmental services provided by framework forestry should not be underestimated, particularly watershed protection. Selected uses of individual framework tree species are described in Part 9.

Table 5.3 Selecting the best of the "failures" - example of a ranking system applied to field performance data to select species for experiments to improve silvicultural treatments.

	Survival		Height		Crown Width		
Tree Species	Mean (%)	Rank	Mean (m)	Rank	Mean (m)	Rank	Total Rank
A	60	6	1.3	5	1.52	5	16
B	42	4	1.4	6	1.61	6	16
C	55	5	1.2	4	1.48	4	13
D	40	3	0.9	1	1.20	2.5	6.5
E	35	1	1.1	3	1.20	2.5	6.5
F	39	2	1.0	2	0.89	1	5



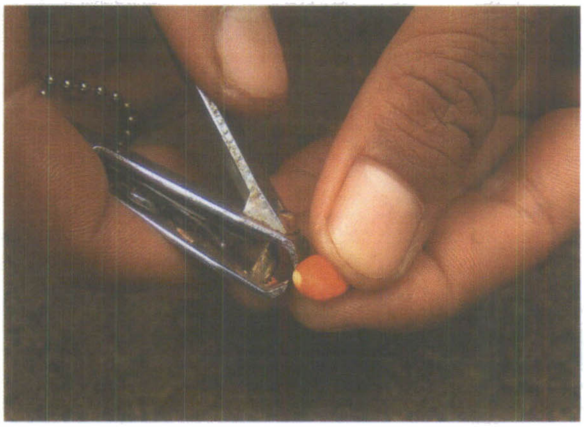
PART 6

Growing Your Own Trees

* *

Designing and Building a Tree Nursery
Collecting Seeds
Handling Fruits and Seeds
Germinating Seeds
Potting Seedlings
Caring for Tree Seedlings in Nurseries
Quality Control

Working in the Nursery - Processing Seeds



Top left - Seeds are easily extracted from the woody indehiscent pods of Cassia fistula *by gently hitting them with the flat blade of a machete.*

Top right - The method also works for the tough but fleshy fruits of Trewia nudiflora. *Removing fruit flesh prevents fungal infection.*

Above - Nicking the soft coat of Ormosia sumatrana *seeds with nail clippers greatly accelerates germination. It is one type of scarification.*

Above - Sowing seeds in modular trays makes it easy to monitor germination rates.

Right - A white marker pen is used to keep track and count each seed that germinates.

Growing Your Own Trees

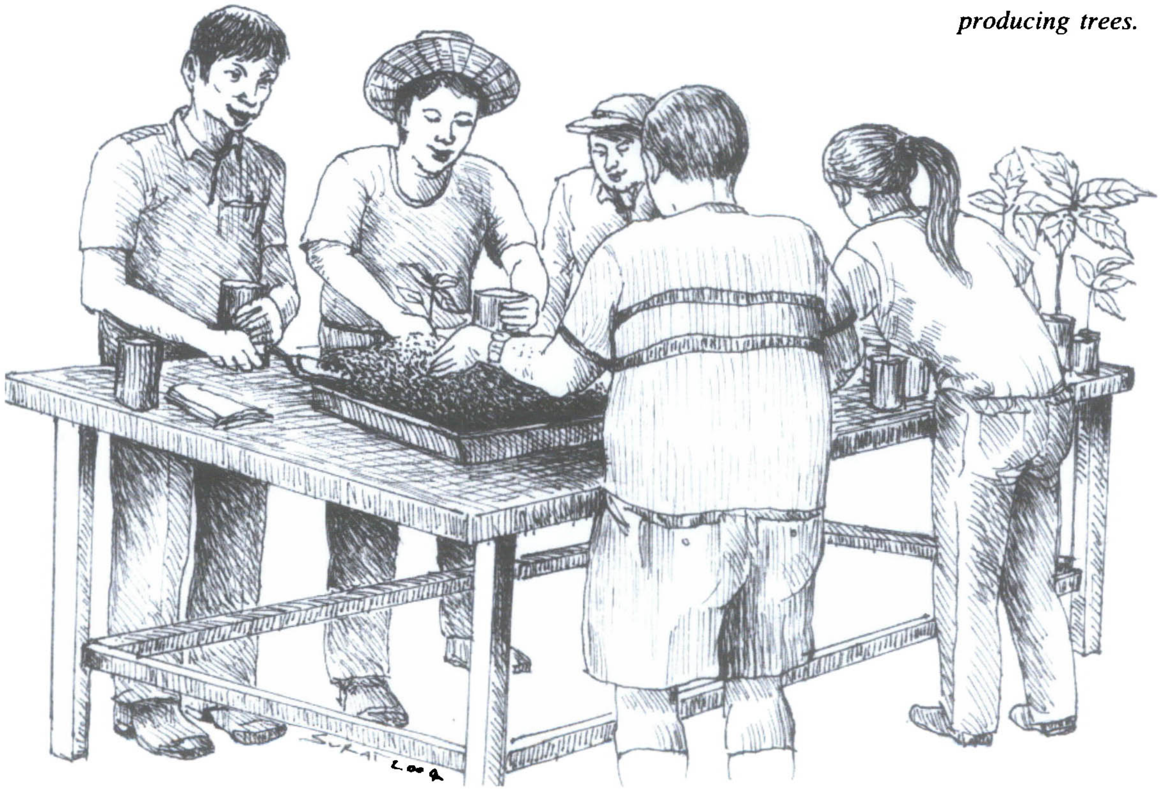
A vital consideration, when planning a forest restoration project, is obtaining high quality trees for planting. Although, commercial nurseries may stock some economic tree species, they rarely grow framework trees. So, for forest restoration, growing trees in community nurseries may be the only option. Although establishing a tree nursery requires a lot of effort, it has many advantages over buying in trees from existing nurseries:

- The community controls all aspects of tree production, including species selection, quality and quantity of trees produced and production costs.
- The community takes pride in the trees produced and, therefore, takes good care of them.
- The nursery becomes a focal point for educational and social activities, which encourage greater community involvement in forest restoration projects.
- Community tree nurseries can be established close to planting sites, so transportation costs and damage to the trees when moving them are minimized.

When any group of people starts a tree nursery, a lot more happens than just the production of trees. The community spirit is strengthened, social relationships develop and participants learn as much about each other as they do about trees and forests.

In this Part, we present the basic skills and knowledge needed to produce mixed crops of framework tree species in small-scale nurseries, of the kind that can be easily managed by a community or by the staff of a protected area. Although the techniques described have been scientifically tested in northern Thailand, they are probably suitable for neighbouring regions, especially with some experimentation to adapt them to local conditions.

Starting a community tree nursery is as much about building a social concensus for environmental conservation as it is about producing trees.



SECTION 1 - DESIGNING AND BUILDING A TREE NURSERY

A nursery must provide ideal conditions for the growth of tree seedlings, whilst protecting them from stresses. It should also provide a comfortable and safe place for nursery workers.

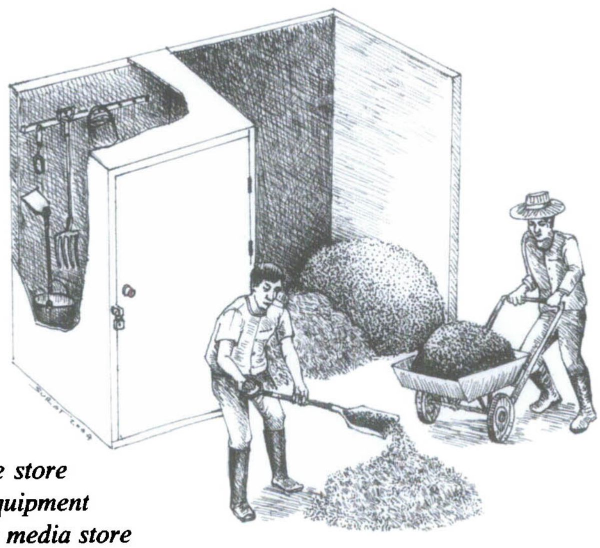
Where should a nursery be built?

A nursery site should be protected from extrèmes of climate. It should be:

- flat or slightly sloping, with good drainage (steeper slopes require terracing);
- sheltered and partially shaded (a site protected by existing trees is ideal);
- close to a permanent supply of clean water (but free from the risk of flooding);
- large enough to produce the number of trees required and to allow for future expansion;
- accessible by motor vehicle for convenient transportation of young trees and supplies and
- close to a supply of suitable soil.

How much space is needed?

The size of the nursery ultimately depends on the size of the area to be planted, which in turn determines how many trees must be produced each year. Other considerations include seedling survival rates and growth rates (which determine how long plants must be kept in the nursery).



A lockable store to keep equipment safe and a media store are essential parts of a tree nursery.

The table opposite relates the size of the area to be planted per year to the size of the nursery required. These calculations refer to seeds germinated in trays and transplanted into containers. For example, if the area to be planted is 4 rai per year, 2,000 seedlings will be needed, requiring a nursery of approximately 50 m^2.

What are the essential features of a tree nursery?

A tree nursery need not be costly. Locally available materials, such as recycled wood, bamboo and palm leaves can all be used to build a simple inexpensive nursery. The essential requirements include:

- a shaded area with benches for seed germination, protected from seed predators by wire mesh;
- a shaded area where potted seedlings can be grown until ready for planting (shade should be removable to allow hardening of the young trees prior to planting);
- a work area for seed preparation, pricking-out etc;
- a reliable water supply;
- a lockable store for materials and tools;
- a fence to keep out stray animals and
- a shelter and toilet for staff and visitors.

How should the nursery be designed?

Careful consideration of nursery layout can greatly increase tree production efficiency. Think about the various activities to be carried out and the movement of materials around the nursery. For example, position container beds near to the main access point, where trees will eventually be loaded on to vehicles before planting. Likewise place the lockable store and media store near the potting area.

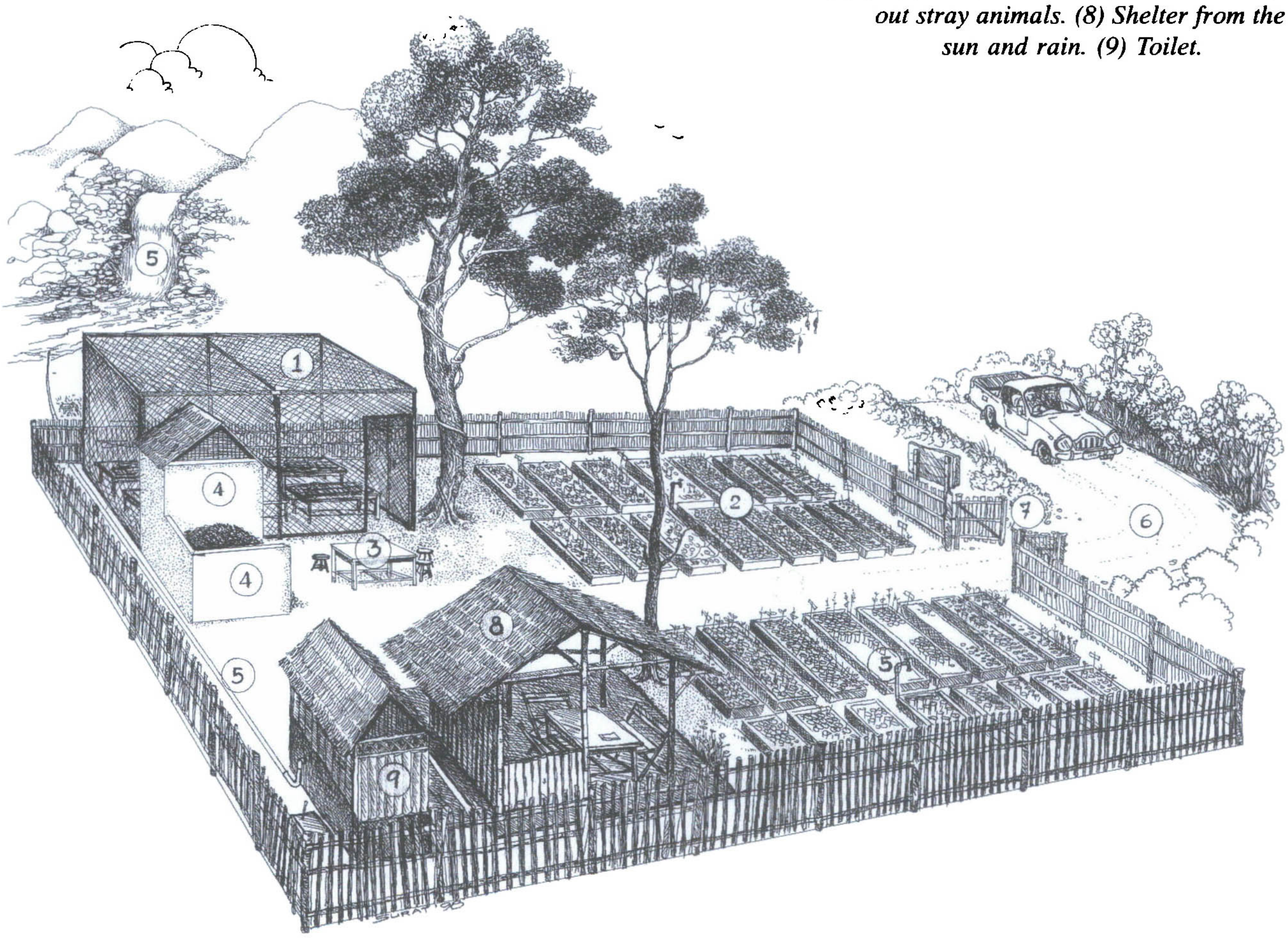
Table 6.1 The space needed for a tree nursery depends on the size of area to be planted each year.

Area to be planted (rai/yr)[1]	Number of trees needed	Seed germination area (sq m)	Standing-down area[2] (sq m)	Storage, shelter, toilet *etc.* (sq m)	Total nursery area needed (sq m)
1	500	2	7	15	24
2	1,000	4	14	15	33
4	2,000	8	28	15	51
20	10,000	40	140	15	195
40	20,000	80	280	15	375

[1]6.25 rai = 1 ha

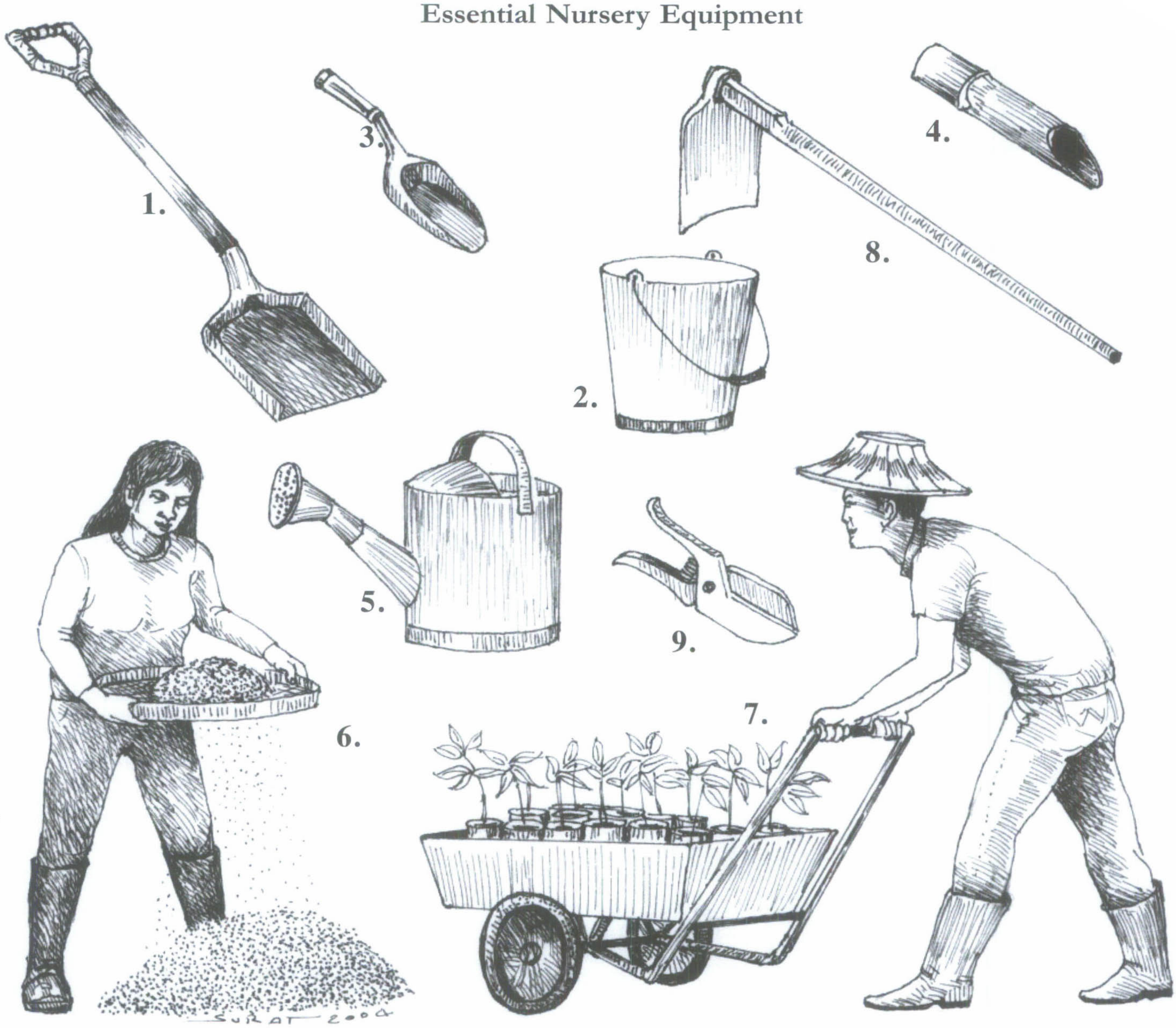
[2]An additional area of similar size for hardening-off seedlings might be required if removal of shade from the area for containerized seedlings is not possible.

Nursery Design



Essential features of a simple tree nursery: (1) Germination shelter protected from seed predators. (2) Standing-down area (shade removed). (3) Potting work area. (4) Medium store and lockable equipment store. (5) Reliable water supply. (6) Easy access. (7) Fence to keep out stray animals. (8) Shelter from the sun and rain. (9) Toilet.

Essential Nursery Equipment



What tools are required?

Growing trees requires simple, inexpensive equipment. Many of the items illustrated above will already be available in an average agricultural community and could be borrowed for nursery work:

- shovel (1) and buckets (2) for collecting, moving and mixing potting media;
- trowels (3) or bamboo scoops (4) for filling containers with potting medium;
- a watering can (5) and hose, both with a fine rose;
- spatulas or spoons for pricking-out seedlings;
- a sieve (6) for preparing the potting medium;
- a wheelbarrow (7) for moving plants and materials around the nursery;
- hoes (8) for weeding and maintaining standing-down area;
- secateurs (9) for pruning seedlings and
- a ladder and basic construction tools for erecting shade netting *etc.*

Section 2 - Collecting Seeds

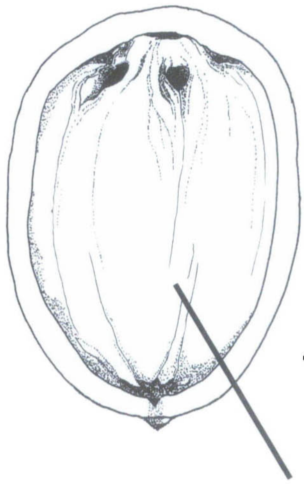
What are fruits and seeds?

The structure sown in a germination tray is not always just the seed. Sometimes the whole fruit is sown *e.g.* the nuts of oaks and chestnuts (Fagaceae) or sometimes it is the pyrene. Pyrenes consist of one or several seeds enclosed within the hard inner wall of the fruit (endocarp). For example, up to five seedlings can emerge from a single pyrene of *Spondias axillaris.* Germination of seeds within pyrenes can be difficult, since the pyrene wall prevents water from penetrating the seed(s). So, a basic understanding of fruit and seed morphology can be helpful in deciding appropriate pre-sowing seed treatments.

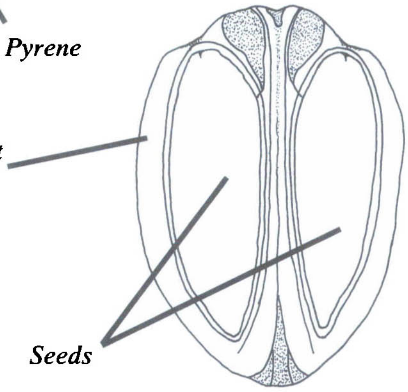
A seed develops from a fertilized egg cell (ovule) contained within the ovary of a flower, usually after pollination and fertilization. Being the products of sexual reproduction, during which the genes of the two parents are combined, seeds are an essential source of genetic diversity within tree populations.

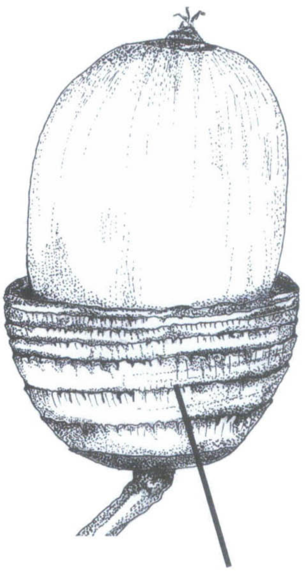
Seeds consist of three main parts: the covering part, the storage part and the embryo. The seed coat or testa protects seeds from harsh environmental conditions and plays an important role in dormancy. Food reserves, to sustain metabolism during and immediately after germination, are stored in the endosperm or the cotyledons. The embryo consists of a rudimentary shoot (plumule), a rudimentary root (radicle) and seed leaves (cotyledons).

Fruits are derived from the ovary wall. They may be broadly classified as "simple" (from the ovary of a single flower); "aggregate" (from the ovary of a single flower, but several fruits fused into a larger structure) or "multiple" (from ovaries of several flowers fusing). Each broad category contains several fruit types.

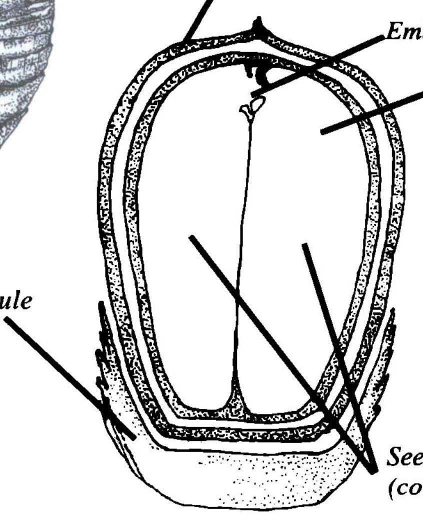


It is impractical to extract seeds from the fruits of Spondias axillaris, *so after removing the outer fruit flesh, the whole pyrene is sown, including the inner fruit wall (endocarp) enclosing up to five seeds.*

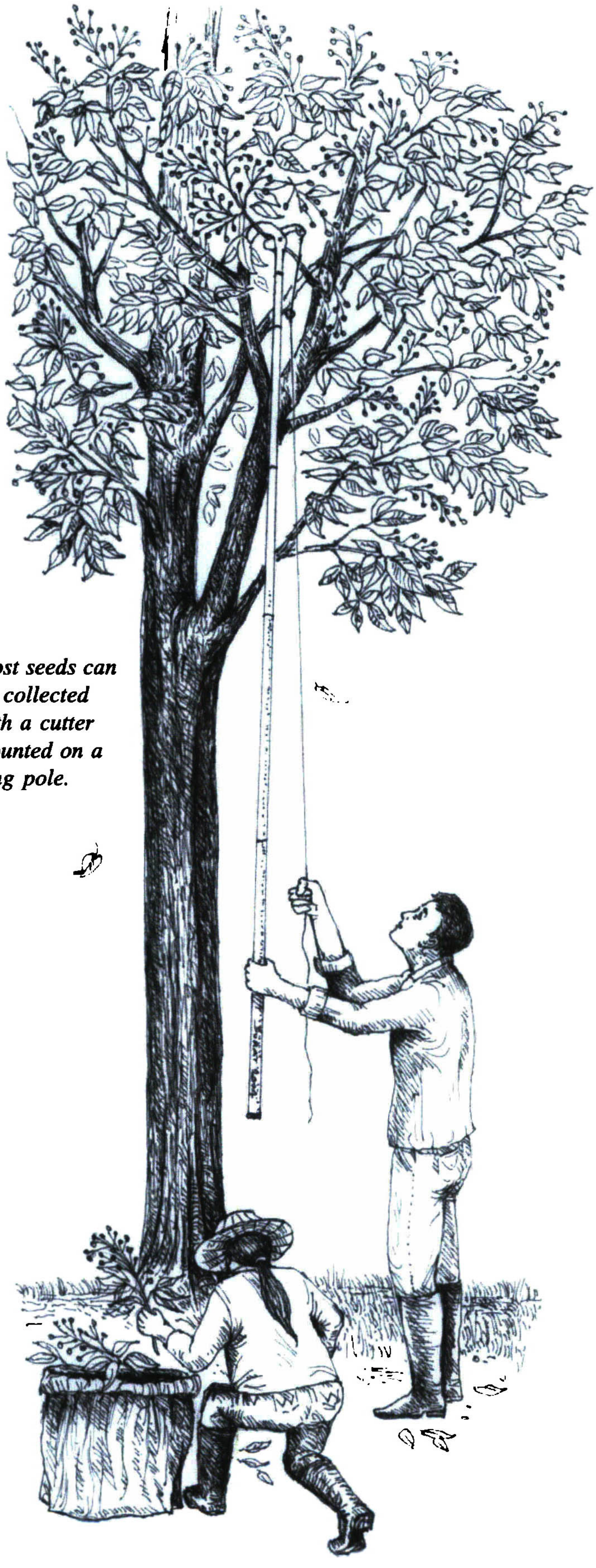




Acorns are the particular form of nuts produced by the genus Quercus *(Family Fagaceae).*



For growing oaks, such as this Quercus semiserrata, *the entire fruit (nut) is sown (after removing the cupule). Nuts are fruits with woody outer walls, which do not split open to release the single seed inside (drawn by Susan Doust).*



Most seeds can be collected with a cutter mounted on a long pole.

When should seeds be collected?

In the seasonally dry forests of northern Thailand, many tree species fruit in every month of the year, so at least one seed collection trip is needed every month. Fruiting peaks at the end of the dry season and at the end of the rainy season (see Fig. 3.1), whereas reduced numbers of fruiting tree species in the early rainy season means that fewer seed collection trips are needed then.

For northern Thailand, the fruiting months of individual tree species can be found in Part 9 of this book and also in Maxwell and Elliott (2001). For other regions, phenology studies are needed.

Find seed trees in the forest and monitor them frequently, from flowering onwards, to judge the best time to collect fruits. Collect fruits once they are fully ripe but just before they are dispersed or consumed by animals. Seeds collected too early will be undeveloped and fail to germinate, whereas those collected too late may have lost viability.

For fleshy fruits, ripeness is usually indicated by a change in the colour of the fruit usually from green to a brighter colour, to attract seed-dispersing animals (*e.g.* the fruits of *Prunus cerasoides* turn from green to red). If animals are seen eating the fruits, it is a sure sign that the seeds are ready for collection. For dehiscent fruits, ripeness occurs when they start to split open (*e.g. Erythrina subumbrans*).

It is usually better to cut fruits from the tree branches rather than to pick them up from the ground.

Climb the tree to cut down ripe fruit. Use a safety harness and never do this alone. A more convenient method of seed collection is to use a cutter mounted on the end of a long pole. Fruits can also be dislodged by shaking the whole tree or some of the lower branches.

For very tall trees, collecting fruits from the forest floor may be the only option. If so, make sure the seeds are not rotten, by cutting them open and looking for a well developed embryo, and/or a solid endosperm (if present). Do not collect any fruits or seeds with signs of fungal infection, teeth marks from animals or small holes made by seed-boring insects. Collect fruits/seeds from the forest floor, when the first truly ripe fruits begin to fall.

Where should seeds be collected and from how many trees?

Genetic variability is essential to enable species to survive in changeable environments. Maintaining it is one of the most important considerations in any tree planting programme for biodiversity conservation. It is therefore crucial that planted trees are not all closely related. The best way to prevent this is to collect seeds from at least 10 parent trees. If seeds are collected from just one, or a few trees, all the seedlings are essentially siblings. Once they mature in the planted plots, they may inbreed with each other, reducing genetic variability in subsequent generations. Cross-pollination with unrelated trees can restore genetic diversity, but only where such trees grow near to planted sites.

Various international organizations advise that to maintain genetic diversity in tree planting programmes, seeds should be collected from as many trees as is practicable (preferably 25-50), situated as close as possible to the planting site. Equal numbers of seeds from each seed tree should be mixed together prior to sowing to ensure equal representation of all the seed trees.

How many seeds should be collected?

The number of seeds collected depends on the number of seedlings required, seed germination percentage and seedling survival rates. Keeping accurate records will help determine the numbers required in future collections.

What precautions should be taken when collecting seeds?

Seed collection trips require planning and liaison with the people responsible for treating and sowing the seeds, because the seeds are vulnerable to desiccation and/or fungal attack, if they are not processed quickly. Sow seeds as soon as possible after collection. Do not leave them in sun, where they may dry out and do not leave them in damp places, where they may rot or germinate prematurely.

What information should be recorded when collecting seeds?

Each time you collect seeds from a new species, give that species a unique species number. Nail a numbered, metal tag on to the tree, so that you can find it again. Collect a specimen of leaves and fruits for species identification. Place the specimen in a plant press, dry it and ask a botanist to indentify the species. Use a pencil to write the species name (if known), date and species number on a label and place the label inside the bag with the seeds.

On a data sheet (example below), record essential details about the seed batches collected and what happens to them from collection time until they are sown in germination trays. This information will help to determine why some seed batches germinate well, whilst others fail and thus improve seed collection methods in the future.

Species number: **Batch number:**

<u>SEED COLLECTION RECORD SHEET</u>

Family:

Species: **Common name:**

Date collected: **Collector's name:**

Tree label no.: **Tree girth:**

Collected from ground [ ] or from tree [ ]

Location: **Elevation:**

Forest type:

Approximate no. seeds collected:

Storage/transport details:

Pre-sowing treatment: **Sowing date:**

Voucher specimen collected [ ]

<u>Notes for herbarium label</u>

SECTION 3 - HANDLING FRUITS AND SEEDS

How should fruits be processed before collection?

Seeds of most tree species are usually removed from their fruits and cleaned before sowing. Failure to remove fruit pulp, for example, encourages fungal infection. The type of processing required depends on the fruit type.

Fleshy fruits

Remove as much flesh as possible with a knife and wash off remaining flesh with water. Soak firm fruits, such as *Melia toosendan*, in water for 2-3 days to soften the pulp sufficiently to ease seed extraction. Once the fruit pulp has been removed, seeds may germinate quite quickly, so either sow them immediately, or process them for storage.

Species number: **Batch number:**

GERMINATION RECORD SHEET

Species:

Date sown: **Number of seeds sown:**

Germinated	Date	Days since sowing
First seed		
Median seed		
Final seed		

Number germinated: **% Germination:**

Pricking-out date:

No. seedlings pricked out:

Date	No. Germinated	Date	No. Germinated

In some species, removal of the pulp reveals a pyrene containing one or more seeds (*e.g. Prunus cerasoides* and *Spondias axillaris* respectively). If seeds are to be planted immediately, crack open the tough woody endocarp to allow water to penetrate into the embryo and trigger germination. Use a vice, hammer or knife to gently crack open pyrenes without damaging the seed(s) inside.

Dry dehiscent fruits

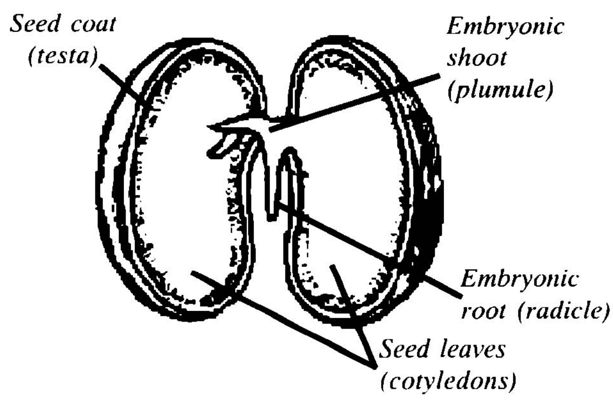
Dry dehiscent fruits, such as pods of trees in the Leguminosae family (*e.g. Erythrina subumbrans*), split open naturally, so lay them out in a dry, sunny place until they open naturally and the seeds either fall out on their own or can be easily shaken out.

Dry indehiscent fruits

Dry fruits that do not split open naturally (*e.g. Cassia fistula*) must be cut open or prized apart with secateurs or other tools.

Seeds of some indehiscent fruits, such as samaras and nuts, are not usually extracted. Place whole fruits in germination trays. In some cases, remove fruit appendages for easier handling *e.g.* the wings of samaras (*e.g. Acer* spp) and the cupules of nuts *e.g.* of acorns or chestnuts (*Quercus* spp and *Castanopsis* spp, respectively, Family Fagaceae).

Seed Structure



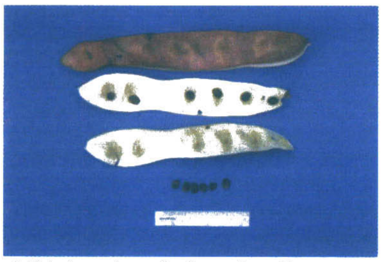
Fruit Types of Some Native Forest Tree Species of Northern Thailand

Sarcosperma arboreum *(drupe)*

Shorea siamensis *(nut)*

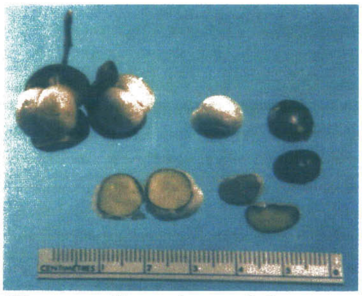
Anneslea fragrans *(capsule)*

Quercus semiserrata *(nut)*



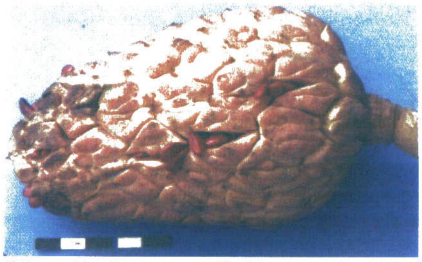
Albizia odoratissima *(pod)*

Phoebe lanceolata *(drupe)*



Heynea trijuga *(capsule)*

Cratoxylum formosum *ssp.* pruniflorum *(capsule)*



Manglietia garrettii *(aggregate capsules)*

Ficus auriculata *(syconium)*

Alstonia scholaris *(capsule)*,

Aphanamixis polystachya *(capsule)*

Archidendron clypearia *(pod)*

Castanopsis acuminatissima *(nut)*

Lithocarpus elegans *(nut)*

Knowing which fruit type you are dealing with can help you decide on effective treatments to remove seeds from the fruit, break dormancy and maximize germination.

Working in the Nursery - Potting

Top left - Mixing soil with peanut and coconut husks produces a well-structured potting medium with good drainage.

Top right - Lift seedlings fom the germination tray with a spoon, holding them by a leaf, so as not to damage the stem.

Place the seedling in a container and top up with potting medium.

Bang the container on the ground to settle the medium and top up again if necessary.

Why should seed be stored?

Storing seeds usually reduces their viability, so in most cases, sowing seeds immediately after collection is the best strategy. However, seed storage may be necessary for three reasons.

Firstly, seed storage allows seeds of framework tree species to be distributed to areas where they may be unavailable.

Secondly, seed storage can shorten the length of time that fast-growing tree species need to be kept in nurseries. Sowing seeds immediately after collection sometimes results in seedlings of faster-growing trees reaching a plantable size several months before the optimum planting time. Such seedlings must be pruned to prevent them from outgrowing their containers and they must be stored in the nursery for several months, wasting space and resources. Storing the seeds of such species for a few months before sowing them enables seedlings to be grown to the optimum size just in time for the planting season.

Thirdly, some tree species produce large fruit crops in some years and no fruits in others (*i.e.* masting). Obviously, for such species, storing seeds collected during masting years for sowing in non-masting years enables a steady supply of seedlings to be maintained.

During seed storage, the main objective is to maintain seed viability. So seed must be protected from insect attack or fungal infection and held in an environment, which reduces seed respiration and metabolism."Orthodox" seeds can be stored easily in dry, cool (or even refrigerated) conditions and still maintain their viability for a long time. On the other hand, "recalcitrant" seeds pose considerable problems.

What's the difference between orthodox and recalcitrant seeds?

Orthodox seeds may be dried to a very low moisture content, without significantly reducing their viability. They can also be stored at low temperatures (usually a few degrees above freezing).

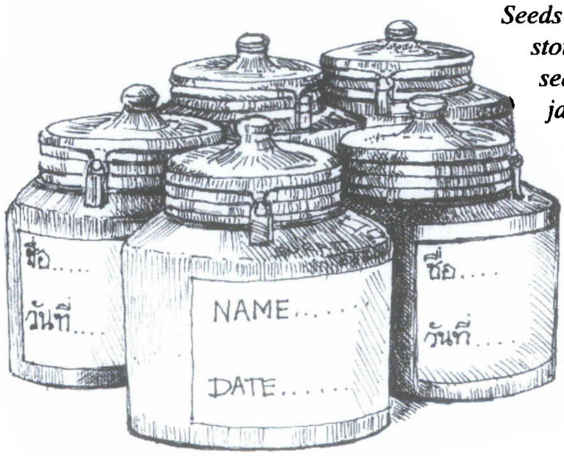
In contrast, recalcitrant seeds are much more sensitive to drying and chilling. Some have no dormancy at all and are relatively short lived. Most cannot be dried to moisture contents lower than 60-70% and they cannot be chilled. The opportunity to store recalcitrant seeds is therefore very limited and usually requires technologies that are impractical in simple village tree nurseries. So, if you want to experiment with seed storage, first try to confirm from the literature that the seed species you want to work with is orthodox.

How can orthodox seeds be stored?

Storage of dried seed at ambient temperatures should be sufficient to maintain viability for 12 - 24 months. Longer periods of storage may require low temperatures, but this is usually not necessary for most short-term forest restoration needs.

Slowly dry seeds in the sun, over several days, to at least 5-10% moisture content, but preferably lower. This reduces the metabolism of the seeds and prevents growth of fungi. To make sure that the required level of dryness has been reached, weigh a small sample of seeds and place them in an oven at 120-150°C for an hour. The weight of the seed sample, after it has been removed from the oven, should not have decreased by more than 10%. Throw away the sub-sample of seeds used to confirm dryness.

Immediately after seeds have been dried, place them in airtight containers. Fill containers to the top with seeds to minimize the volume of air (and moisture) trapped inside them. Efficiently sealing containers is crucial, to prevent any moisture or fungal spores from entering. If containers are likely to be opened frequently, store seeds in small sealed packets within larger containers, to minimize exposure of remaining seeds to air and moisture. Putting a small sachet of silica gel in containers helps maintain dryness.



Seeds should be stored in well-sealed, labelled jars with as little air as possible.

How can seed dormancy be shortened?

Dormancy protects seeds during dispersal and ensures germination at the optimal time of the year in their natural habitat (see Part 3). However, for efficient tree production in nurseries, immediate germination is often requried. In the forest, dormancy is a survival mechanism; in the nursery, it unnecessarily prolongs tree production time. Therefore, after seeds have been extracted from fruits, various treatments may be applied to break dormancy. The treatment used for each species depends on the particular dormancy mechanism(s) present.

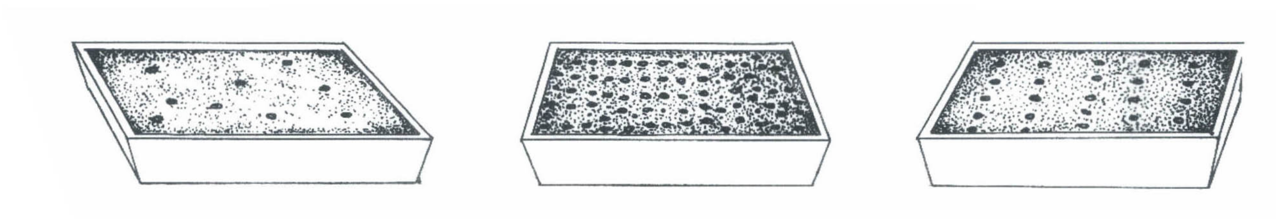
Germination is triggered when the embryo inside the seed absorbs water. A thick, impervious seed coat can prevent this, so one of the simplest techniques to break dormancy is to cut away a small piece of the seed coat with a sharp knife or nail clippers. For smaller seeds, gently rubbing them with sandpaper can be equally effective. These techniques are called scarification. During scarification, great care must be taken not to damage the embryo within the seed. Soaking seeds in hot water or sulphuric acid can have a similar effect, but there is a greater risk of damaging the embryo with these treatments.

Some species have "mechanical" dormancy *i.e.* the seed coat is too strong for the growing seedling to push through. For such species, acid treatment is recommended. Acid can kill the embryo, so seeds must be soaked in acid only long enough to soften the seed coat, without penetrating to the embryo.

In some seeds, germination is inhibited by chemicals, which must be removed to break dormancy. Chemical inhibitors can be present in the pulp of fleshy fruits, so simply ensuring complete removal of fruit pulp may solve this problem. However, if the inhibitors are within the seed, they must be washed out. Repeated soaking and drying is the appropriate treatment.

Some suggested treatments to break seed dormancy for each framework tree species are presented in Part 9. For other species, try some simple experiments. Apply various treatments to replicate batches of 50-100 seeds (at least 3 replicates per treatment) and compare mean germination percent and median length of dormancy (Part 3, Section 5) with "control" replicates (no treatments applied) placed next to each treatment replicate. Use paired t-tests to analyse the results.

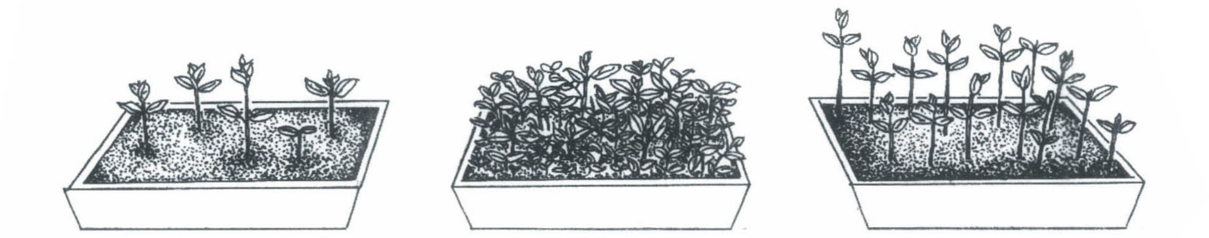
Sowing Density



Too sparse - a waste of space and resources in the nursery.

Too dense - creates ideal conditions for the spread of diseases. Seedlings shade each other and compete for nutrients.

Just right - allows air circulation between the seedlings and reduces competition among them.



SECTION 4 - GERMINATING SEEDS

Germination consists of three overlapping processes. Absorption of water causes swelling of the seed and splitting of the seed coat. Food reserves are mobilized (from the endosperm) and transported to the embryonic root (radicle) and shoot (plumule) (see p 82), which begin to grow and push against the seed coat. The final stage is actual emergence of the radicle and plumule through the seed coat. In germination trials, seeds are counted as having germinated when the radicle and/or plumule can be seen emerging.

Sowing seeds is the final stage of seed handling, and marks the start of the growing process. The time of seed sowing is determined by the fruiting time of each particular species or, in the case of stored seeds, the estimated growing time required in the nursery.

The three major factors that influence seed germination are moisture, temperature and light. It is important to maintain environmental conditions that will encourage rapid and synchronous germination. Seedlings are at their most vulnerable just after germination. They are particularly susceptible to disease, mechanical damage, physiological stress and predation. Consequently, great care has to be taken to avoid these problems.

How can I ensure high quality seeds are sown?

It is very important to sow only the highest quality seeds available. They should have no signs of fungal growth, teeth marks from animals or small holes made by seed-boring insects, such as weevils. For larger seeds, a quick way to get rid of the dead ones is to throw the seeds into a bucket of water and wait for 2-3 hours. Skim off the ones that remain floating; as they have air inside instead of dense cotyledons and a functioning embryo. Sowing poor quality seed is a waste of time and space, and may encourage the spread of disease around the nursery.

How should seeds be sown?

Sow seeds into germination trays, filled with a suitable medium. The trays should be 6-10 cm deep, with plenty of drainage holes in the bottom. The germination medium must provide support for the germinating seedlings until they are ready for pricking-out and have good aeration and drainage. Seedling roots need to breathe, so the germination medium must be porous. Too much water fills the air spaces in the medium and suffocates seedling roots. It also encourages disease. Compacted soil inhibits both germination and seedling growth. Therefore, forest soil must be mixed with organic materials such as rice or coconut husk to create a well-structured medium.

FORRU-CMU recommends using a mixture of two thirds forest soil to one third coconut husk. A mix of 50% forest soil with 50% coarse sand is more suitable for small seeds, especially those susceptible to damping-off (*e.g. Ficus* spp). It is important to include some forest soil in the medium, since it provides a source of mycorrhizal fungi, which are very beneficial to the growth of young tree seedlings. Do not add fertilizer to the seed germination medium.

Sow small to medium-sized seeds just below the surface of the medium, to a depth of approximately two to three times their diameter. This protects seeds from predators and drying out and prevents them from being washed away during watering. If rats or squirrels are a problem, then cover germination trays in wire mesh.

If the seeds are sown too closely together, the seedlings may be weakened, and more susceptible to disease. Space the seeds at least 1-2 cm apart (more if the seeds are large) to prevent over-crowding. Water the germination trays lightly, immediately after sowing the seeds and regularly thereafter. Use a spray bottle or a watering can with a fine rose to avoid compacting the surface of the medium. Watering too frequently encourages fungal and bacterial diseases. Place the trays in shade to reduce drying out and scorching of leaves.

Larger seeds with high germination rates (*e.g. Quercus semiserrata*) can be sown directly into individual containers, filled with potting medium.

How can damping-off be prevented?

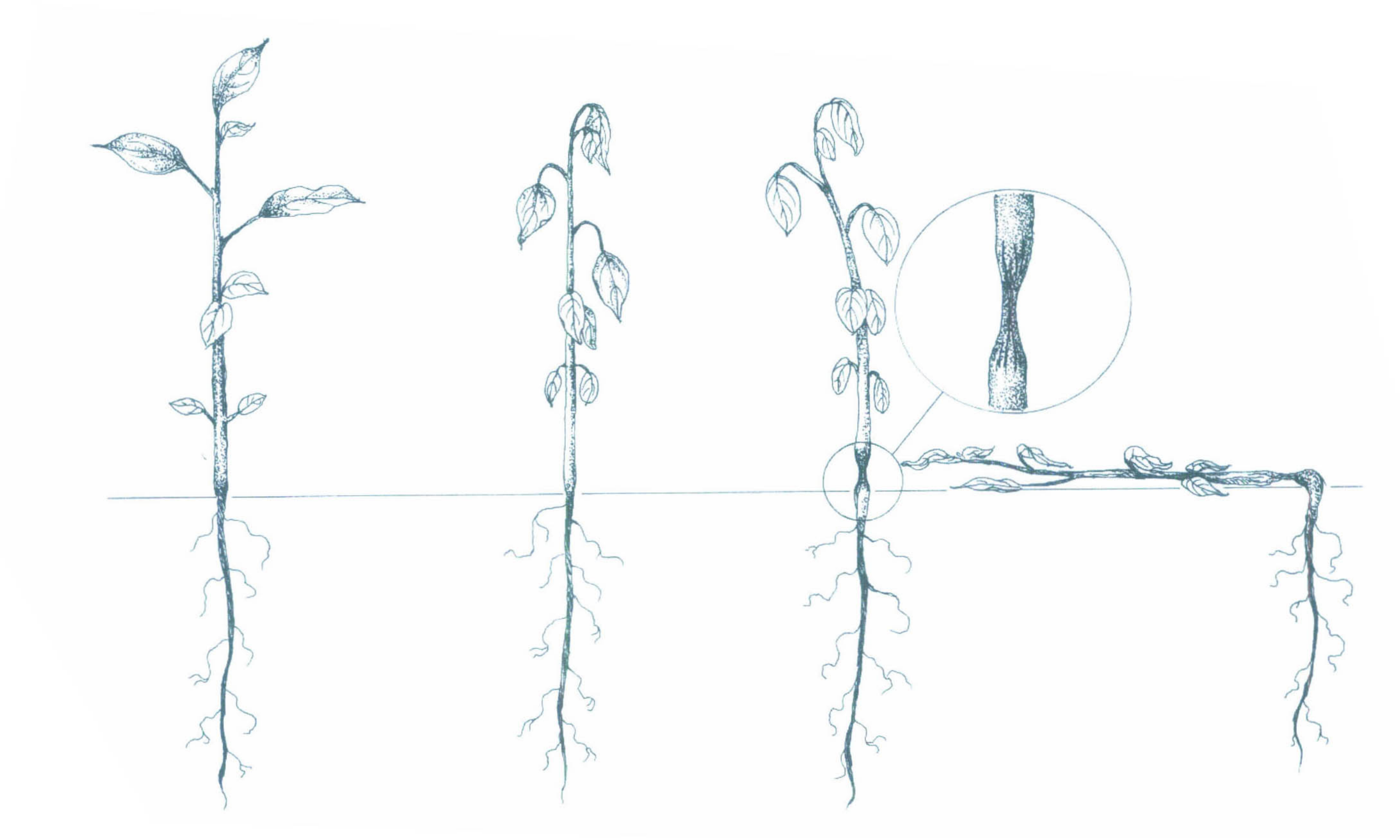
The term "damping-off" refers to a wide range of soil-borne diseases, which attack seeds, pre-emergent sprouts and young seedlings. Pre-emergence damping-off causes seeds to become soft and turn brown or black. Recently germinated seedlings are most vulnerable to post-emergence damping-off in the soft stem tissue at or just above the soil surface. Infected seedlings look like they have been pinched at the base of the stem, which turns brown.

If damping-off disease becomes a serious problem, apply a fungicide. Although use of chemicals is never desirable, prompt application of small quantities of fungicide at the outbreak of disease could mean the difference between saving an entire tree crop or having to wait another year to collect seeds again.

Seeds may be pre-soaked (dressed) in Captan or Thiram to reduce the incidence of damping-off. Once a seedling has become infected, it must be removed from the germination tray immediately and destroyed, to prevent the disease from spreading. Basic hygiene measures can significantly reduce the incidence of damping-off diseases and reduce the need to apply fungicides. These include; not sowing seeds too densely, maintaining a well-structured germination medium, not over-watering, ensuring free air movement around the seedlings and disinfecting any nursery tools that have come into contact with soil.

For species that are particularly susceptible to damping-off, particularly *Ficus* spp, FORRU-CMU recommends using a germination medium of 50:50 sand:forest soil, without coconut husk, since there is some evidence that it may increase the risk of damping-off. Apply Captan to the soil surface, when the seeds are sown and again one month afterwards.

Damping-off Disease



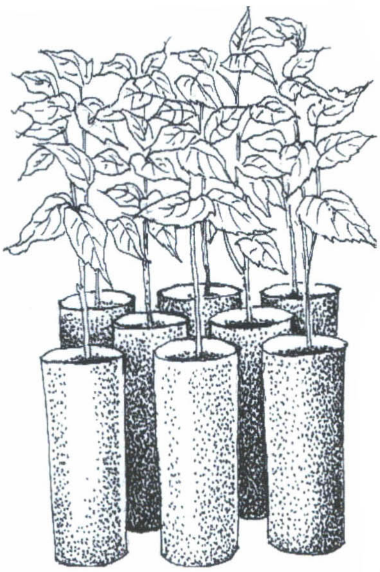
Damping-off disease, caused by various fungi, often first manifests itself with the appearance of brown lesions on the stem, at or just above the soil surface. The lesions spread and the leaves begin to wilt. Finally the stem collapses and the seedling dies.

Section 5 - Potting Seedlings

Should seedlings be grown in containers or soil beds?

There are two ways to grow tree seedlings: i) in containers (containerized) and ii) in beds of soil (bare-rooted). Containerized seedlings are preferred for forest restoration projects, since digging up seedlings from a soil bed and transporting them to the planting site in a bare-rooted state increases transplantation shock. An experiment carried out by FORRU-CMU found significantly lower growth amongst bare-rooted seedlings compared with containerized ones, during the first year after planting out.

With a containerized system, seedlings are first germinated in trays and then transplanted into containers for "growing on", until they grow large enough to be planted out. Containers protect the trees during transportation to the planting site. Within the container, the root ball remains intact and in contact with soil the whole time during transportation and planting, thus minimizing transplantation stress.



Black plastic bags (9 x 2½ inches) are cheap but not reusable and can cause root curling.

What kind of containers are recommended?

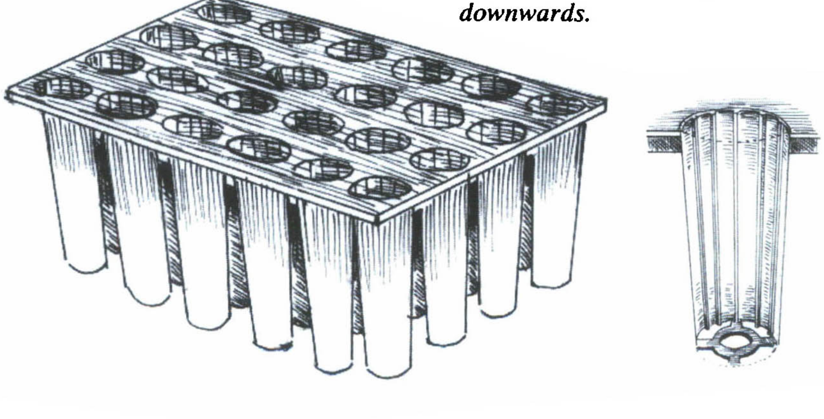
Containers must be large enough to allow development of a long and dense root system. They must have sufficient holes to permit good drainage, be lightweight, inexpensive and readily available.

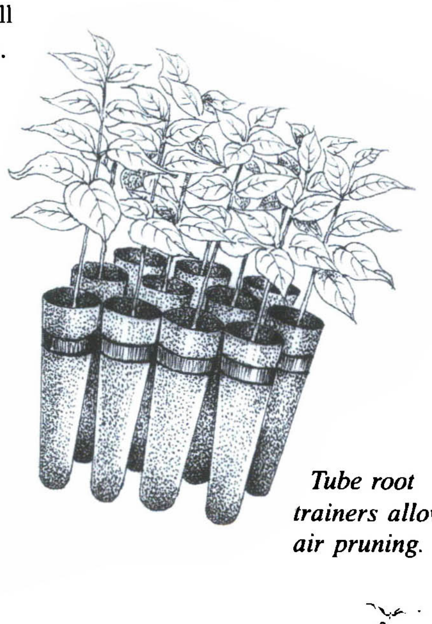
Black plastic bags (9 x 2½ inches) are strong, lightweight, cheap and effective and have been used successfully at FORRU-CMU with a wide range of species. However, they do have some disadvantages. The bags can bend easily, particularly during transportation, which may damage the root ball, causing it to crumble during planting. Root spiralling may occur at the base of the bag, increasing vulnerability of the tree to wind-throw later in life. Roots can grow through the drainage holes into soil beneath, so that roots are severed when the tree is lifted. These problems can be minimized by following the nursery practices described in Section 7.

How useful are root trainers?

Root trainers are rigid plastic pots with grooves down the sides to direct root growth downwards thus preventing root spiralling. REX trays, made in Thailand, are recommended. They consist of blocks of 24, tough, plastic pots with vertical grooves and large holes in the bottom to allow air pruning (see Section 7). Although initially more expensive than bags, they can be reused many times and their rigidity protects the root ball during transportation.

REX tray root trainers have deep longitudinal grooves to direct root growth downwards.





Tube root trainers allow air pruning.

What makes a good potting medium?

The potting medium consists of solid particles with pores between them for aeration and drainage. The medium must physically support a vigorously growing tree and supply the roots with oxygen, water and nutrients.

The roots of trees growing in containers have access to only the limited volume of medium in the container. Forest soil alone is unsuitable as a potting medium, because it is easily compacted and the container prevents free drainage. This causes water-logging, which suffocates roots. Good drainage is essential, but the medium must also retain enough water to supply the plants between watering times.

Although forest soil alone is a poor potting medium, some forest soil should always be included in the medium, since it carries the spores of mycorrhizal fungi that help tree seedlings to grow.

To prevent compaction, mix forest soil with bulky organic matter *e.g.* rice husk charcoal, coconut husk, peanut husks or coarse sand or try making your own compost from locally available organic waste. Mixing forest soil with these ingredients will "open out" the medium and improve drainage and aeration. Whichever materials you choose, they should be locally available throughout the year and cheap.

Sieve the soil and organic materials to remove large lumps and stones and mix them together on a hard, flat surface using a shovel. Store the medium in a moist condition.

One medium that has been used successfully at FORRU-CMU for many species consists of forest soil, peanut husk and coconut husk, mixed in the ratio of 2:1:1.

Never re-cycle the potting medium. When disposing of weak or diseased seedlings, the potting medium, in which they grew, must also be discarded well away from the nursery, to prevent the spread of diseases.

Box 6.1 – Alternatives to seeds: 1. Wildlings

Growing a mixed crop of framework tree species from seeds takes at least 18 months. Waiting for trees to fruit and for seeds to germinate requires great patience. So, is there a faster way to produce framework tree saplings? Wildlings are seedlings dug up from the wild and cultivated in a nursery. Forest trees produce vast numbers of surplus seedlings, most of which die. So, digging up a few for transfer into a nursery does not harm the forest ecosystem. Transplanting wildlings from a cool, shady forest directly into an open deforested site usually kills them. So wildlings must be potted, cared for in a nursery and hardened off before planting-out. At FORRU-CMU, Kuarak (2002) determined how to use wildlings to produce framework trees for planting:

"In the forest, locate a suitable parent tree of the required species, which fruited heavily the previous fruiting season. Dig up seedlings, no taller than 20 cm (larger ones have high mortality due to severe transplantation shock), within a 5-m radius of the parent tree (those seedlings would die anyway from competition with the parent tree). To minimize damage to the root system, do this at the beginning of the rainy season, when the soil is soft.

Prune the wildings, just after digging them up, to significantly reduce mortality and increase growth rate. Cut back the stem by one third to one half. Make a 45° cut about 5 mm above an axillary bud and cut back remaining leaves by about 50%. Trim secondary roots until seedlings can be potted easily into 9 x 2½-inch black plastic bags, filled with the standard potting mix described above, without bending the tap root.

Keep the potted wildlings under deep shade (20% of normal sunlight) for about 6 weeks. Then, follow the same procedures described below for care and hardening-off saplings grown from seed.

Compared with producing planting stock from seed, these techniques can shorten the time needed to grow trees to a plantable size by several months to a year."

How much potting medium is needed?

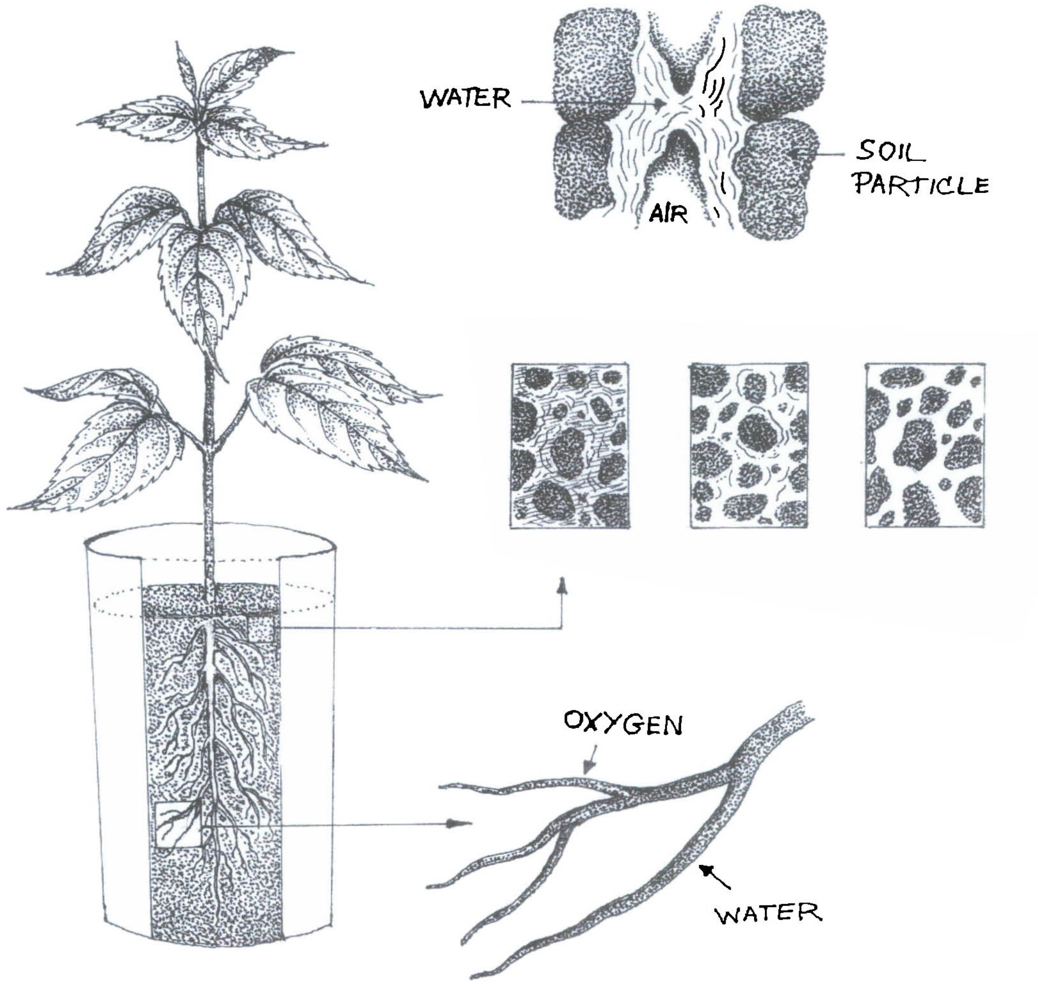
Do not underestimate the amount of soil and other materials required. For example, for approximately 2,000 black plastic bags (9 x 2½ inches), 1 m^3 of forest soil plus 1 m^3 of organic materials are required. Measure the radius and height of the containers you are using and apply the following formula:

Total volume of medium required = (container radius)^2 x container height x 3.142 x nunber of containers.

How do I fill containers with potting medium?

First, make sure the medium is moist, but not too wet. Spray it with water if necessary. For pricking-out small seedlings, fill containers to the brim with medium using a trowel or bamboo scoop. Bang each container on the ground a few times to allow the medium to settle. Then, top up containers with more medium until they are full again. The medium should not be so compact as to inhibit root growth and drainage, but neither should it be too loose. Plastic bags should stand up straight, unsupported. With plastic bags, check for correct consistency by firmly grasping the bag. The impression of your hand should remain after you let go.

Medium Properties



Spaces or "pores" are just as important as solid particles in a potting medium. Interconnected pores of different sizes deliver both water and oxygen to the root system. Mixing soil with organic materials (e.g. husk of coconut, peanut or rice) creates a medium of ideal porosity.

Box 6.2 – Alternatives to seeds: 2. Cuttings

For tree species that fruit rarely, or for those with seeds that are difficult to germinate, planting stock can sometimes be produced from cuttings. Trees grown from cuttings often mature early – a desirable "framework characteristic". However, since cuttings are clones of the trees from which they are collected, they must be collected from many trees, to maintain genetic diversity. Commercial nurseries use high-tech mist propagation systems to mass-produce trees from cuttings, but excellent results can be achieved with simpler methods. Longman and Wilson (1993) provide a guide to these, but bear in mind that little work has been done on vegetative propagation of most forest tree species in Thailand, and for many, vegetative propagation may be difficult, especially if juvenile shoots are not readily available. However, for her PhD at FORRU-CMU, Vongkamjan (2003) successfully adapted a simple method, using plastic bags, for some of northern Thailand's framework tree species:-

"Cut medium-sized, vigorous juvenile shoots (such leafy shoots can often be found on stumps after chopping or burning) from several trees with a sharp, clean pair of secateurs. Place them in plastic bags with a little water and take them to a nursery immediately . In the nursery, trim cuttings into 10-20 cm lengths. Remove lower, woody parts and the fragile apical section. If each node has a leaf or bud, single nodes can be used, but for cuttings with short internodes, lacking buds, the cutting can include 2-3 nodes. Cut back the leaves transversely by 30-50%. Cut the bases of the cuttings into a heel shape just below a node. Immerse the prepared cuttings in a solution of the fungicide Benlate (3 g/10 l) for 5-10 minutes. Try experimenting with these steps to stimulate rooting. For example, retaining the apical meristem and varying the leaf area may be effective.

Hormone treatments are usually required to stimulate the cuttings to root. Each species responds differently to the various hormone preparations that are available, so some experimentation may be necessary. Products containing the artificial auxins, IBA and NAA in various concentrations are most likely to be effective. These products are usually powders, which should be dusted lightly on the bases of the cuttings. Follow the instructions on the packet.

Species	Rooting (%)	Best Rooting Treatment
Colona flagrocarpa	63	IBA 8000
Bebregeasia longifolia	68	Seradix 3
Eurya acumminata	18	Seradix 2
Ficus hirta	45	Seradix 2
Ficus superba	72	IBA 3000
Macaranga kurzii	25	Seradix 2 & 3
Morus macroura	90	None
Saurauia roxburghii	65	Seradix 3
Trema orientalis	48	None

Mix 50% sand with 50% rice husk charcoal to make a rooting medium and place it in small, black, plastic bags. Push the bases of the cuttings into the medium. Water the medium and press it to make it firm around each cutting. Put groups of 10 small bags into larger plastic bags (20 x 30 cm). Add one litre of water and seal the larger bag. This provides an atmosphere with 100% humidity, until roots grow to feed water to the cuttings' shoots. Label each bag with the species name and starting date. Keep records of how many cuttings develop roots and shoots. Top up the bags with water weekly if needed and remove dead cuttings and dried leaves. Once cuttings show vigorous root and shoot development, transplant them into 9 x 2½ inch plastic bags"... (and care for them as described in Section 6).

Bags within bags to maintain 100% humidity, while the cuttings grow roots.

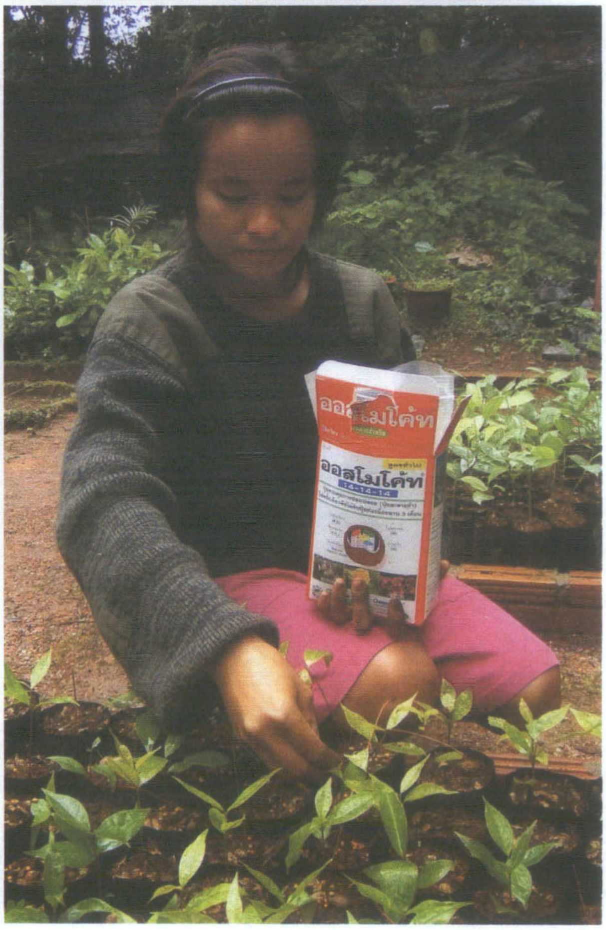
Working in the Nursery - Caring for Seedlings

Below and right - Root pruning is necessary to prevent roots from growing into the soil beneath containers. It also encourages root branching and development of a compact ball of fine roots within the container.

Above - Standing-down. Edging standing-down beds with bricks or bamboo helps keep the containers upright.

Below left - Watering is a skilled art. A fine rose produces small water droplets, which prevent soil compaction.

Below right - Applying a slow release fertilizer (Osmocote) to accelerate seedling growth - only 10 granules every 3 months is enough.



WORKING IN THE NURSERY - CARING FOR SEEDLINGS

Top left: Noctuid caterpillar on Balakata baccata. *Remove by hand (wear gloves) or use insecticide.*

Top right: Remove weeds well before they grow this dense.

Middle right: Mosses and liverworts invading containers are an indication of over-watering.

Middle left: Rust fungus on Morus macroura. *Remove infected plants or spray fungicide.*

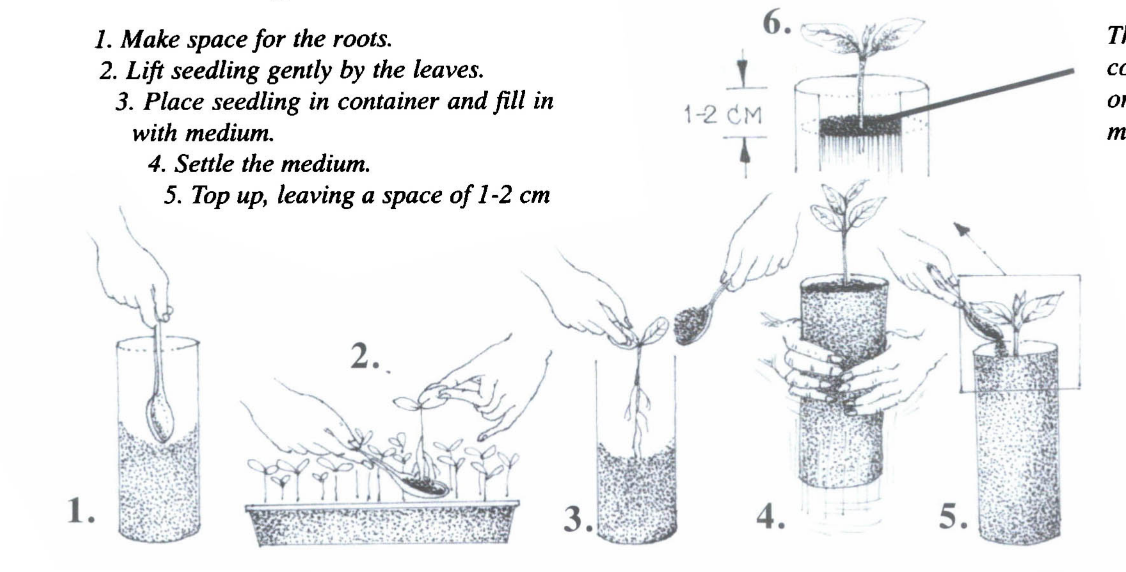
Above: Grading is a form of quality contol.

Left: Monitoring growth and mortality of samples of seedlings enables nursery managers to develop efficient production schedules.

Pricking-out

1. Make space for the roots.
2. Lift seedling gently by the leaves.
3. Place seedling in container and fill in with medium.
4. Settle the medium.
5. Top up, leaving a space of 1-2 cm

The seedling's root collar should be at or just below the medium surface.

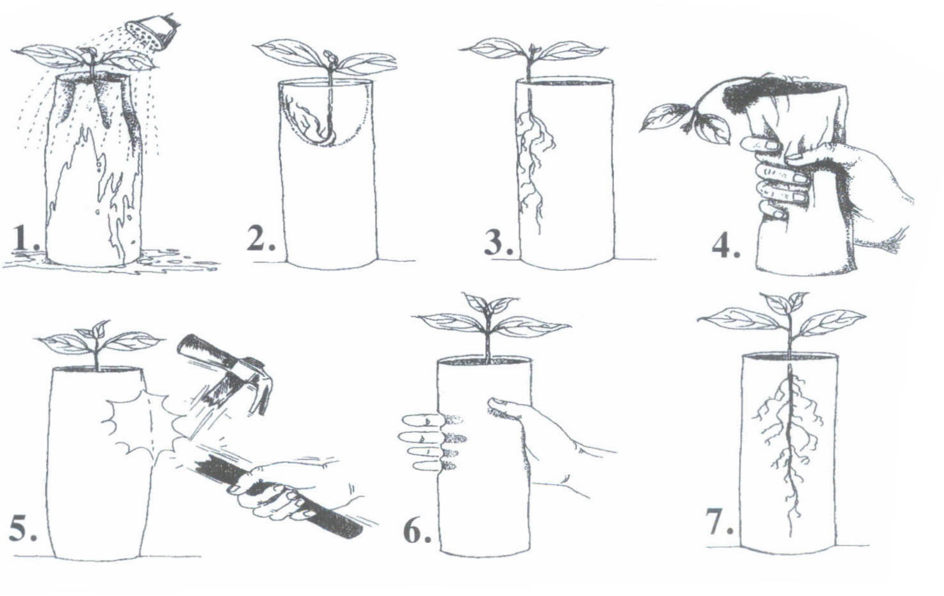


What is "pricking-out"?

"Pricking-out" (potting) is transferring seedlings from germination trays into containers. Do this in shade, late in the day. Fill containers as previously described. Make a hole in the medium, big enough to take the seedling's roots without bending them. Handle the fragile seedlings with care. Gently grasp a leaf (not stem) of a seedling and slowly prise it out of its germination tray with a spoon. Place the seedling's root into the hole in the potting medium and fill the hole with more medium. Bang the container on the ground to settle the medium. Top up with more medium, until the medium surface is 1-2 cm below the container's rim and the seedling's root collar is at the medium surface. Then, press the medium to make sure the plant is upright and centrally placed. With larger plants, partly fill containers with medium. Place plants in containers and add medium around the roots.

What is standing-down"?

"Standing-down" refers to the time that containerized seedlings are kept in the nursery – from potting until transportation to the planting site. After potting seedlings, place containers in a shaded area and water the seedlings with a weak solution of urea (1 dessert spoonful of urea per 20 litres of water) twice per day for 2 weeks. If using plastic bags, make sure that they are placed upright and take care not to squeeze them together. At first, the containers can be touching each other (*i.e.* "pot thick"), but as the seedlings grow, space the containers a few centimetres apart, to prevent neighbouring seedlings from shading each other. Separate rows of containers with strips of bamboo. A layer of gravel in the standing-down bed helps with drainage and makes root pruning easier.



Problems with Potting

1. Medium has settled; rim of plastic bag collapses, blocking watering.
2. Curled roots will make the adult tree susceptible to wind throw.
3. Seedling not placed centrally.
4. Medium too soft.
5. Medium compacted.
6. Excellent medium consistency.
7. The perfectly potted seedling!

Section 6 - Caring for Tree Seedlings in Nurseries

How much shade is necessary?

After pricking-out, place seedlings under about 50% shade to prevent scorching of the leaves and wilting. Shade netting called "slan", graded according to the percent shade cast, can be bought at most agricultural supplies stores. Hang it on a frame 0.5 - 2.5 m above the seedlings. If slan is unavailable or too costly, local materials, such as coconut palm leaves, thin strips of bamboo or even dried grass are also effective. However, take care not to provide too much shade with these materials. More than about 50% shade will produce tall, weak seedlings, which are susceptible to disease.

Even when well established in containers, seedlings are still vulnerable to high temperatures and full sunlight. Consequently, they are usually grown under light shade until they are ready for hardening-off.

How often should seedlings be watered?

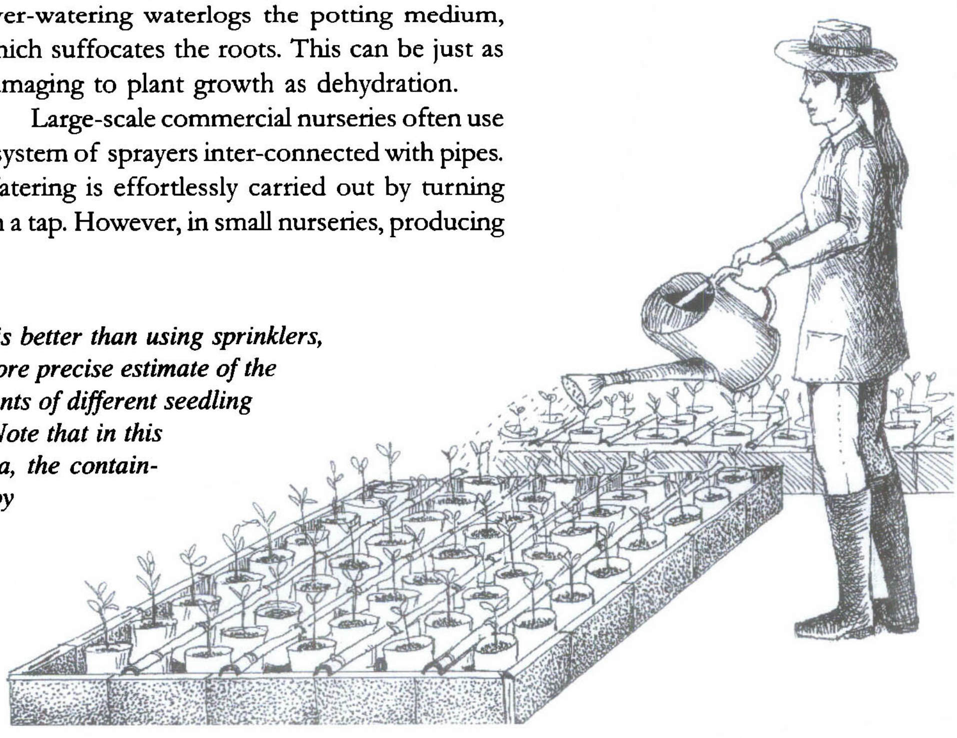
Watering is one of the most important tasks in nurseries. It is a skilled job, and should be recognized as such. Each container holds a relatively small amount of water, so seedlings can dry out rapidly, if watering is interrupted for more than a day in the dry season. In contrast, over-watering waterlogs the potting medium, which suffocates the roots. This can be just as damaging to plant growth as dehydration.

Large-scale commercial nurseries often use a system of sprayers inter-connected with pipes. Watering is effortlessly carried out by turning on a tap. However, in small nurseries, producing a wide range of native forest tree species, with different water requirements, watering by hand, using a watering can or a hose with a fine rose, is recommended. This allows nursery workers to assess the dryness of each batch of seedlings and adjust the amount of water delivered accordingly.

The person responsible for watering the saplings must judge how much water to provide. If the potting medium is still moist, watering may not be necessary that day. If the soil surface is starting to dry out, the saplings are ready for water. Mosses and liverworts, growing on the surface of the potting medium, indicate that the seedlings are being given too much water. They also make it difficult to assess the water status of the medium in each container and so they should be removed and watering reduced.

During the rainy season, in an open nursery, it may be possible to go several days without watering the saplings. In contrast, in the dry season, it may be necessary to water the saplings twice per day.

Watering should be carried out early in the morning or in the late afternoon. It is important that the watering regime is properly implemented. Nursery workers, responsible for watering, should record on a calendar each time watering is carried out.



Watering by hand is better than using sprinklers, since it allows a more precise estimate of the different requirements of different seedling species for water. Note that in this standing-down area, the containers are separated by bamboo strips to prevent over-crowding.

Should fertilizer be applied?

For high growth rates, trees require large amounts of nitrogen (N), phosphorus (P) and potassium (K). They also need moderate quantities of magnesium, calcium and sulphur and trace amounts of other elements *e.g.* iron, copper and boron. There may be adequate supplies of these nutrients in the potting medium but if not, fertilizer must be applied. Your local agricultural extension service or agriculture college may be able to analyze the nutrient in the medium you use and advise you on fertilizer requirements.

The decision to apply fertilizer depends on the growth rate required, or the appearance of the seedlings. In some cases, it may be necessary to accelerate seedling growth, so that seedlings grow tall enough by planting time. Also, weak seedlings, or those with symptoms of nutrient deficiency, such as yellowing leaves, may be suffering from a nutrient shortage.

Slow-release fertilizer granules are recommended. At FORRU-CMU, good results have been achieved by adding about 10 granules of Osmocote NPK 14:14:14 (approx 0.3 g) to each container every 3 months. Nutricote is also recommended. Although slow-release fertilizers are expensive per kilogram, only very small quantities are applied every 3-6 months, so the labour costs of applying them are very low.

Alternatively, ordinary fertilizer (*e.g.* Rabbit Brand 15:15:15) can be used. Dissolve 3-5 g of fertilizer per litre of water and apply with a watering can. Then, water the saplings again with fresh water to wash off any fertilizer solution from the leaves. This treatment must be repeated every 10-14 days, so it requires much more time and labour than using slow-release granules.

Do not apply fertilizer to rapidly growing species that reach a plantable size before the optimal planting time *e.g. Prunus cerasoides*, since it encourages seedlings to outgrow their containers. In addition, nitrogen-fixing species in the Family Leguminosae rarely require fertilizer *e.g. Erythrina subumbrans.*

Do not apply fertilizer immediately prior to hardening-off, as new shoot growth should not be encouraged at this time.

Too much fertilizer can damage roots and if fertilizer particles come into direct contact with plant tissues, chemical burning occurs.

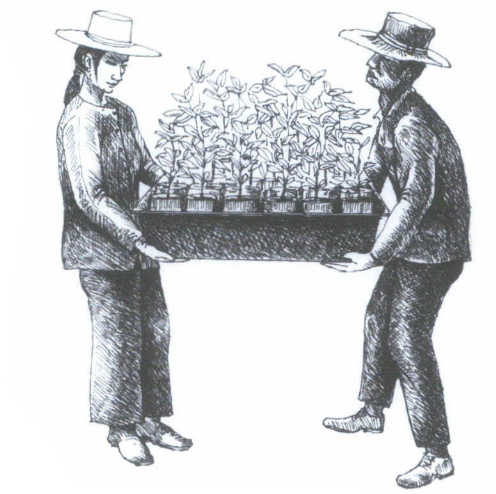
Should a mycorrhizal inoculum be applied?

Research at FORRU-CMU has found that, provided forest soil is included in the potting medium, all forest tree species become naturally infected with mycorrhizal fungi. Liquid and granulated products, containing a mixture of common mycorrhizal fungi species are just becoming available in Thailand, but they are very expensive. Philachanh (2003) found that application of a granulated mycorrhizal inoculum to the roots of seedlings during pricking-out, increased seedling mortality (probably due to disturbance of the root system when applying the product) and did not accelerate growth of surviving seedlings. Therefore, we do not recommend use of mycorrhizal inoculae for the production of forest trees in nurseries at this time.

How should weeds be controlled?

Weeds, growing around the nursery, harbour pests and may produce seeds, which invade nearby containers. So, remove all weeds before they flower.

Any weeds that colonize the containers compete with tree seedlings for water, nutrients and light. Weeds in containers are difficult to remove without damaging tree seedling roots. So, check containers frequently and use a blunt spatula to remove weeds, while they are still small. Also remove any mosses and algae, growing on the medium surface. Controlling weeds with a herbicide is not an option in a nursery full of valuable tree seedlings!



The ultimate achievement of a well-run nursery - a basket of healthy, vigorous saplings ready for planting at the beginning of the rainy season.

What are the causes of disease?

There are three main causes of disease:

- **Fungi**: although some species are beneficial, others can cause damping-off, root rot and leaf-spot (blights and rusts).
- **Bacteria**: most are harmless, but some may cause damping-off, canker and wilts.
- **Viruses**: most are unlikely to cause serious problems in the nursery, but some may cause leaf-spots.

How are diseases detected and minimized?

Constant vigilance is needed to prevent disease outbreaks. Learn how to recognize the symptoms of common plant diseases and inspect the young trees weekly. To prevent disease spread, make sure that the plants are not being over-watered, that there is adequate drainage within and beneath the containers and that the plants are well spaced to allow air movement around them and to prevent direct transfer of pathogens from plants to their neighbours. Use disinfectant to wash tools or rubber gloves that come into contact with the plants.

If a disease outbreak occurs, remove infected leaves or dispose of diseased plants. Burn them well away from the nursery. Do not recycle either the medium in which they grew or plastic bags. If using rigid containers, wash them with disinfectant and dry them in the sun for several days before re-using them.

Routine spraying with chemicals should not be necessary. Chemicals are expensive and they are a health hazard if not handled properly. If it is necessary to spray an infected batch of seedlings, first try to identify the type of disease (fungal, bacterial or viral) and select an appropriate chemical. For example, prodione is active against fungal leaf-spots, whereas Benomyl is a more general fungicide. Captan is particularly effective against damping-off. When using any pesticides, read the health warnings on the packet and follow all the protective precautions recommended.

How can pests be controlled?

Whilst most insects are harmless, some can rapidly defoliate young trees or damage their roots enough to kill them. Not all pests are insects. Nematode worms, slugs and snails and even domestic animals can all cause problems.

The most important pests include leaf-eaters such as caterpillars and crickets; shoot borers, particularly beetle and moth larvae; juice-suckers, such as aphids, mealy bugs and scale insects and root-eaters such as nematode worms. In addition to eating the plants, these pests transmit diseases.

Regular inspection of the growing trees, as recommended above, will alert nursery workers to pest infestations before they get out of control. Remove harmful animals or their eggs by hand, or spray the saplings with a mild disinfectant.

If this fails to prevent an infestation from spreading, then spray the saplings with an insecticide, observing all the health precautions on the packet. Select the most appropriate chemical for the particular pest species present. For example, Pirimicarb is active against aphids, whereas Pyrethrin is a more general insecticide. For weeds, pests and diseases, ***prevention is better than cure.***

Not all pests are small. Dogs, pigs, chickens, cattle and other domestic animals can wreak havoc in a tree nursery in just a few minutes. So, where such animals occur, make sure that the plants are protected within a sturdy fence.

Protect your nursery from pests both large and small. Fence out domestic animals.

What is grading and why is it important?

Grading is an effective method of quality control. It involves arranging the growing trees in order of size, whilst at the same time removing stunted, diseased or weak ones. In this way, only the most vigorous and healthy trees are selected for hardening-off and planting-out. This maximizes post-planting survival. Alternatively, when more space is required in a nursery that is full, the smallest and weakest plants can be easily identified and removed to make room for new seedlings that are likely to grow better.

Carry out grading at least once per month. Root pruning and disease inspection can be carried out at the same time. When carrying out grading or root pruning, wash hands, gloves and secateurs in disinfectant frequently to prevent spreading diseases from one block of plants to another.

Dispose of poor quality plants by burning them, well away from the nursery. Do not recycle the medium or plastic bags. There is sometimes a reluctance amongst nursery workers to throw away poor quality seedlings or saplings. However, keeping them is a false economy, as they waste space, labour, water and other nursery resources that would be more efficiently provided to healthy plants that are more likely to survive when planted out.

Problem Plants

1. This container was knocked over and spent some time lying on its side, resulting in a non-vertical stem.

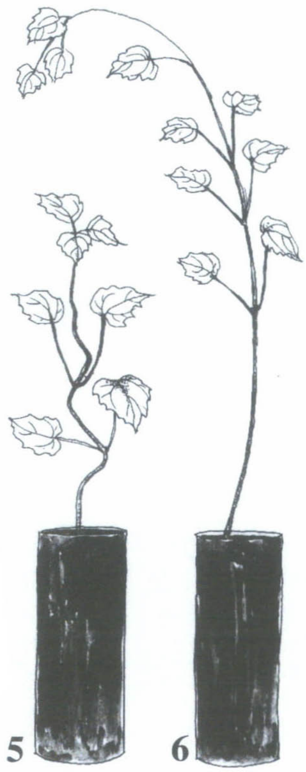
2. This plant is loosing its leaves, possibly as a result of disease.

3. Stunted growth - compared with other plants of same age.

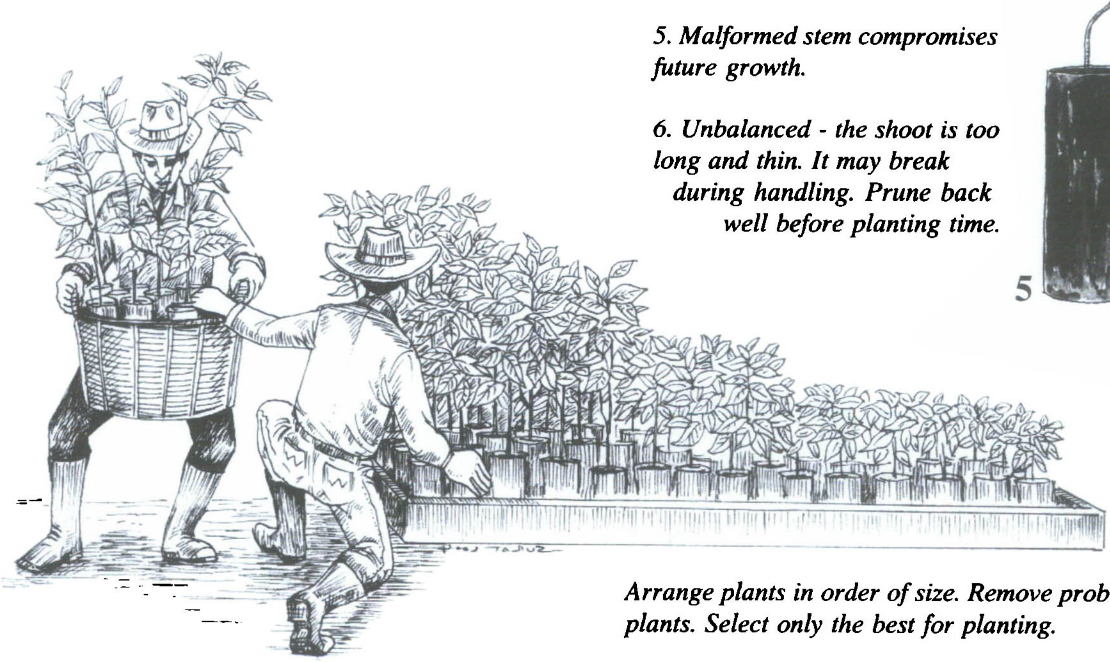
4. Attacked by insects - burn it and spray surviving plants with insecticide.

5. Malformed stem compromises future growth.

6. Unbalanced - the shoot is too long and thin. It may break during handling. Prune back well before planting time.



Grading



Arrange plants in order of size. Remove problem plants. Select only the best for planting.

Section 7 – Quality Control

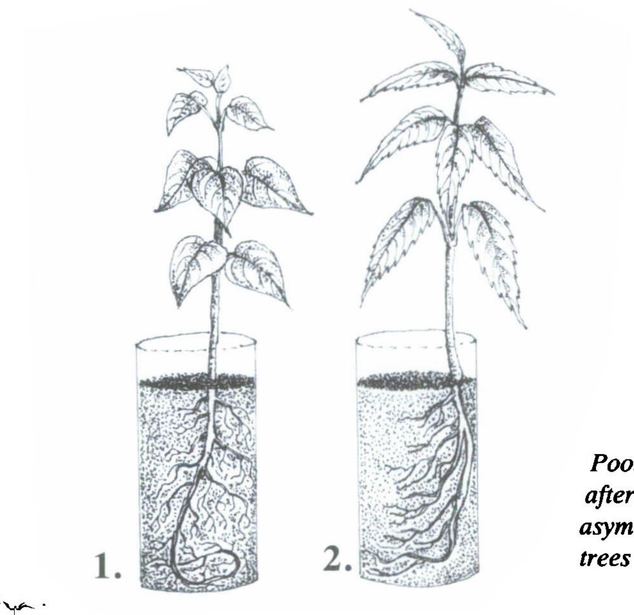
The nursery manager must produce high quality seedlings, which have the best chance of establishing in the field and growing rapidly when planted out in the unforgiving environment of a deforested site. Both the shoot and root systems of young trees should be healthy and in balance with each other. This reduces transplantation stress, tree mortality and the risk of having to replant the following year. It is a false economy and a waste of time to plant poor quality seedlings.

The root system - what are we trying to achieve?

Root systems are far more critical to the ultimate survival of trees than shoot systems are. They are also more vulnerable to damage. Roots must grow into surrounding soil, whilst maintaining a supply of water and nutrients to shoots during establishment. Root growth is affected by the choice of container, the choice of potting medium, the watering regime and by pests and diseases. Root systems of containerized trees, ready for planting, must:

- be free of pests and diseases;
- be densely branching with balance between thick, supporting roots and fine ones, which absorb water and nutrients;
- form a compact root ball, which does not fall apart when the tree is removed from its container;
- **not** be spiralling at the base of the container;
- be able to support the shoot system and
- be inoculated with mycorrhizal fungi.

Root Deformities



Poor root development in containers leads to problems after trees are planted out. Root spiralling (1) and asymetrical development of the root system (2) makes trees vulnerable to wind-throw later in life.

How can a good root system be achieved?

If tree roots grow through the bottom of their containers and into soil beneath, they become broken when containers are lifted at planting time. The young trees go into shock, wilt and may die even before they reach the planting site. This can be prevented by:

- lifting containers frequently and using a clean pair of secateurs to prune back any roots seen growing outside the containers (do this in the late afternoon to minimize moisture loss);
- standing containers on concrete or gravel to inhibit roots growing out and
- scheduling production so that trees are transplanted as soon as they grow large enough.

What is air pruning?

Another way to inhibit root growth outside containers is called "air pruning". Containers are placed on raised wire grids, with plenty of ventilation beneath. Dry air kills any roots that protrude from the containers, so there is no need for manual root pruning. However, the costs saved by not having to prune roots manually must be weighed against the cost of building the wire-grid benches. Both manual and air root pruning stimulate branching of finer roots within containers, thus helping to create a dense root ball.

The shoot system - what are we trying to achieve?

Containerized trees, ready for planting, should have well-balanced root and shoot systems, with very active root growth and a reduced rate of shoot growth. This enables planted trees to overcome transplantation shock and become established in their new environment.

How tall should the saplings be at planting time?

The actual height of saplings is less important than their capacity to produce vigorous new growth. Some fast-growing tree species (*e.g. Erythrina subumbrans, Gmelina arborea, Prunus cerasoides, Melia toosendan etc.*) can be planted out when only about 30 cm tall but for most species, it is better to plant them when they are about 40-60 cm tall. Smaller saplings (less than 30 cm) have much higher post-planting mortality rates than larger ones do, because of competition with weeds, but very large saplings are much more susceptible to transplantation shock.

Is shoot pruning necessary?

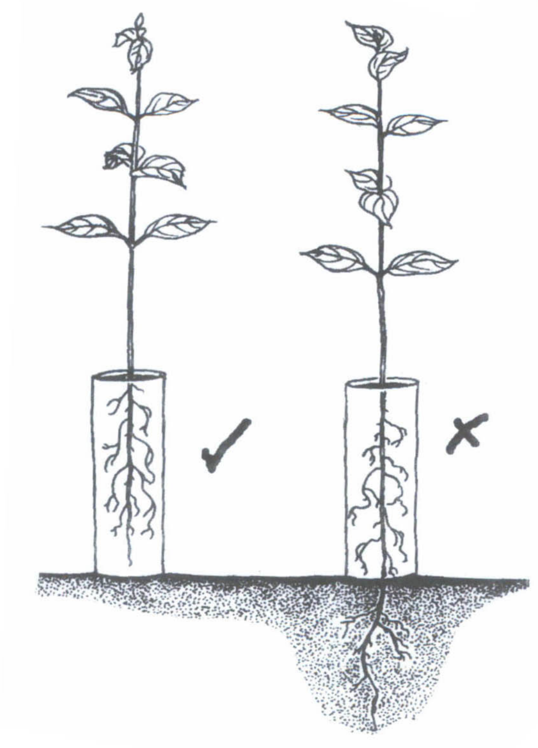
Shoot pruning is necessary for those fast-growing species, which (due to the time of seed availability) have to be kept in the nursery for a long time. Such trees may become too large for their roots to support or too cumbersome to handle during transportation and planting. The stems of tall saplings are easily broken when they are being moved.

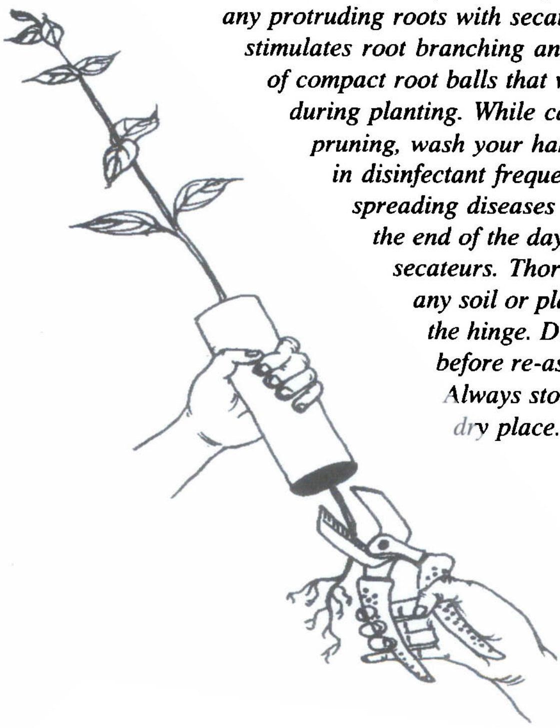
In some species, such as *Erythrina subumbrans* and *Prunus cerasoides*, pruning has the additional benefit of encouraging branching. This is a desirable response since, after planting out, spreading crowns shade out weeds and rapidly form a closed forest canopy.

Never prune shoots within a month before planting out, because it promotes growth of new leaves, just as saplings are about to be stressed by transplantation. Immediately after planting, the root system may not be able to take up enough water to supply new leaves, so anything which stimulates bud break shortly before planting out should be avoided.

Some species do not respond well to pruning or become highly susceptible to fungal infections (*e.g. Melia toosendan, Magnolia baillonii, Balakata baccata, Macaranga denticulata etc.*). So before attempting to prune large numbers of saplings, experiment with a few to test the effects of pruning.

Root Pruning





During grading, lift plastic bags and trim back any protruding roots with secateurs. This stimulates root branching and the development of compact root balls that will not fall apart during planting. While carrying out root pruning, wash your hands and secateurs in disinfectant frequently to prevent spreading diseases among plants. At the end of the day, dismantle the secateurs. Thoroughly clean out any soil or plant material from the hinge. Dry the pieces before re-assembling them. Always store secateurs in a dry place.

What is "hardening-off" and why is it necessary?

Weaning, or 'hardening-off', is the process of preparing saplings for the difficult transition from the ideal nursery environment to the harsh conditions of deforested sites. If they are not toughened up, to cope with the hot, dry, sunny conditions of planting sites, they will suffer transplantation shock and die.

About 2 months before planting, move all saplings to be planted to a separate area in the nursery and gradually reduce shade and the frequency of watering. They should stand in full sunlight for their final month in the nursery.

Watering should be gradually reduced, by approximately 50%. The aim is to slow down shoot growth, and encourage smaller new leaves. Thus, saplings normally watered in the early morning and late afternoon, should be watered just once, in the late afternoon during the hardening-off period. Saplings normally watered once a day should be watered every other day. Do not reduce watering to the point at which leaves wilt, as that stresses and weakens saplings. Regardless of the normal schedule, water the saplings as soon as any wilting is observed.

Species number: **Batch number:**

SAPLING PRODUCTION RECORD SHEET

Species:

Potting Date: **No. Seedlings Potted:**

Fertilizer treatment:

Pruning treatment:

Pests and Diseases:

DISPATCHED

No. of Plants	On Date	To Place	Average Height of Plants

What records should be kept?

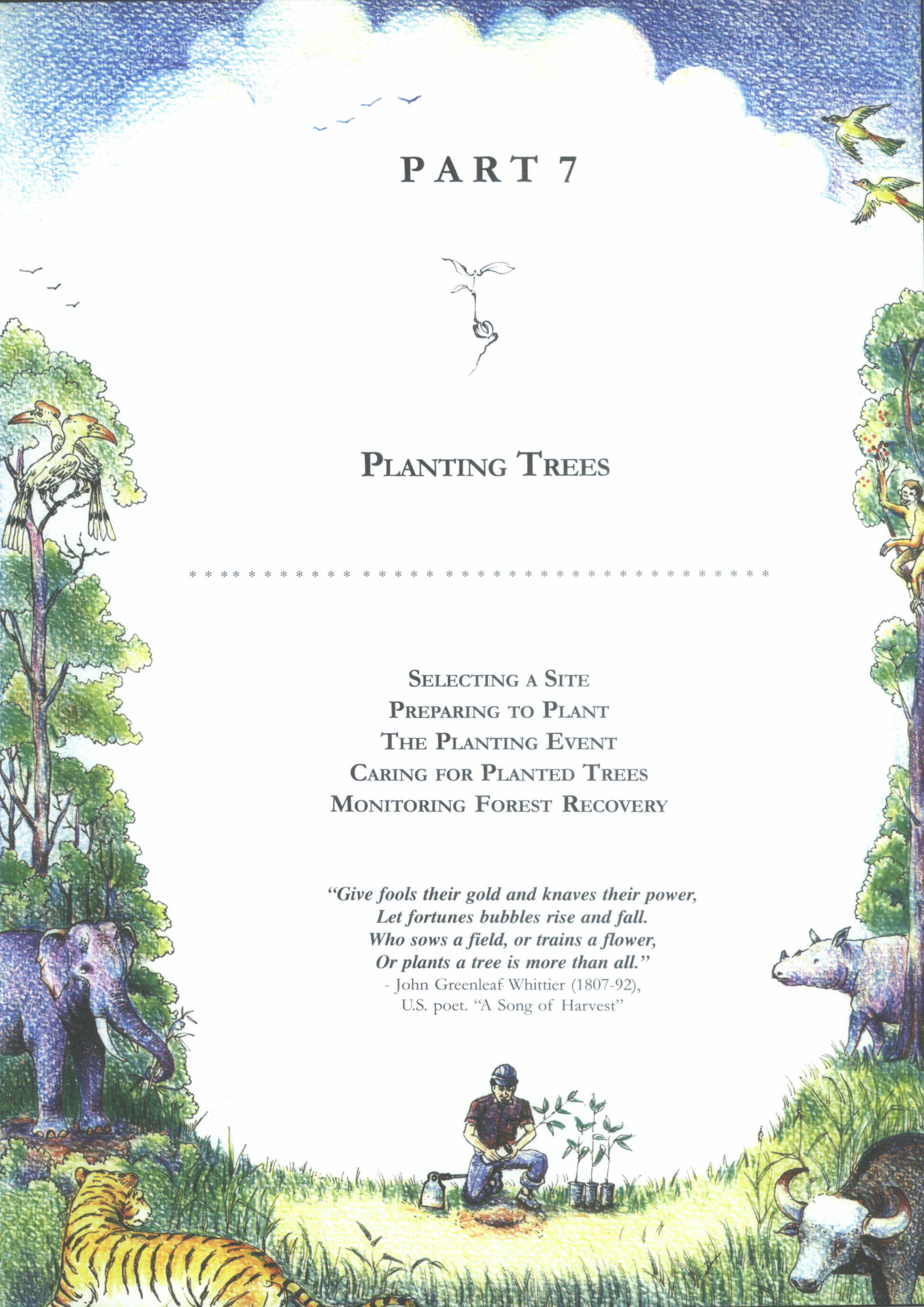
Learning from experience is only possible if accurate records are kept of nursery activities and the performance of each species. Records are essential to prevent new nursery workers from repeating the mistakes of previous ones. They are also used to assess the productivity and achievements of the nursery (numbers of species/saplings grown) and for the development of species production schedules.

Label seed trays and plants in the nursery with species names, batch numbers and dates of seed collection and pricking-out. Use the record sheet formats on pages 81, 82 and below to record when and where each batch of seeds was collected, seed treatments applied, germination rates, seedling growth rates, diseases observed and so on. Finally, record when and to where saplings are dispatched for planting.

What are production schedules?

Growing a wide range of native forest tree species is complicated by scheduling problems. Different species fruit in different months and have different growth rates, yet saplings of all species must grow to a plantable size by the optimum planting time. For example, a fast-growing species, which seeds in January, might be ready for planting in June, if fertilizer is applied after pricking-out. But, if seedlings fail to grow as fast as expected, they will have to be kept in the nursery until the following year, by which time they might outgrow their containers and require pruning.

Based on nursery records, a species production schedule describes how to manipulate seed germination and seedling growth of each tree species to ensure that saplings grow tall enough for planting out by the first or second rainy season after seed collection. It includes details of optimal seed collection time, seed treatments required to break dormancy, time from germination to pricking-out, standing-down time required for adequate sapling growth, optimal fertilizer application, pruning treatments or other steps necessary to manipulate sapling growth. The production schedule is a working document, requiring continual adjustment as variations in seed availability, seedling growth rates and so on become known.



PART 7

PLANTING TREES

SELECTING A SITE
PREPARING TO PLANT
THE PLANTING EVENT
CARING FOR PLANTED TREES
MONITORING FOREST RECOVERY

"Give fools their gold and knaves their power,
Let fortunes bubbles rise and fall.
Who sows a field, or trains a flower,
Or plants a tree is more than all."

- John Greenleaf Whittier (1807-92),
U.S. poet. "A Song of Harvest"

Planting Sites to Maximize Conservation Value

For maximum conservation value, plant framework tree species (A) to link forest patches by creating wildlife corridors; (B) to create permanent forest wherever the risk of soil erosion or landslides is high and (C) to protect water courses, essential to the survival of specialised wildlife such as White-winged Wood-duck (D), otters (E), Fishing Cat (F) and dragonflies (G).

Planting Trees

"He who plants a tree is the servant of God,
He provides a kindness for many generations,
And people he will never see shall bless him."
Henry van Dyke (1852-1933), U.S. poet. "The friendly trees"

Tree planting is undoubtedly one of the most popular activities of forest restoration. At the end of a hard day's work, the sight of degraded land, dotted with newly planted saplings, is immensely rewarding and gives planters the satisfaction of knowing they have done what they can to reverse the destruction of natural resources. However, tree planting is by no means the end of the forest restoration process: long term commitment is essential for success. Whilst it may be easy to mobilize a community for tree planting events, it is often more difficult to maintain motivation to care for the trees after planting. Unless weeds are controlled, fertilizer applied and fires prevented, the hard work of the tree planters and the immense effort expended in the nursery to grow the planted trees may amount to nothing. Forest restoration is a process, not just a tree planting event. Therefore, this Part provides an overview of all those activities that are necessary to ensure the success of forest restoration projects, after the trees have left the nursery.

Section 1 – Selecting a Site

Where should framework trees be planted?

As already explained in Part 5, the framework species method of forest restoration is especially suitable for conservation areas – national parks, wildlife sanctuaries, nature reserves and so on – where biodiversity conservation is a high management priority (although it can also provide forest products where economic benefits are needed). Although cost-effective in the long-term, the method requires a considerable investment of time, labour and money to begin with (see Part 8). Consequently, it makes sense to first select priority sites, where tree planting will yield maximum benefits for ecological integrity, biodiversity conservation and environmental protection.

Such sites include:

- Wildlife corridors to reverse forest fragmentation
- Sites around springs and along stream sides
- Sites at risk of soil erosion and landslides

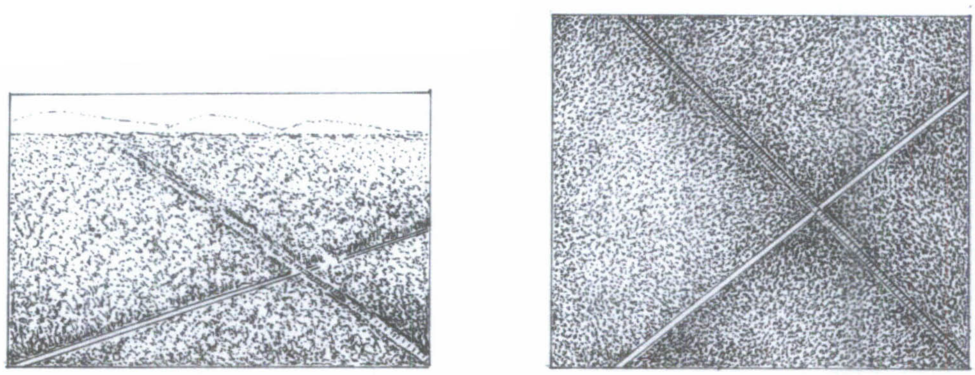
What is forest fragmentation?

Forest fragmentation is when large, continuous areas of forest become dissected by roads, other infrastructure, cultivated land and so on. The small, disconnected forest patches created, then shrink due to further disturbances (*e.g.* chopping, burning *etc.*) eroding them from their edges inwards. Small, isolated populations of plants and animals, living in such tiny forest fragments, are at high risk of extirpation, through inbreeding, diseases and vulnerability to catastrophes (*e.g.* fires) that would not usually threaten the survival of larger populations in larger forest areas. Genetic isolation also increases the risk of extirpation.

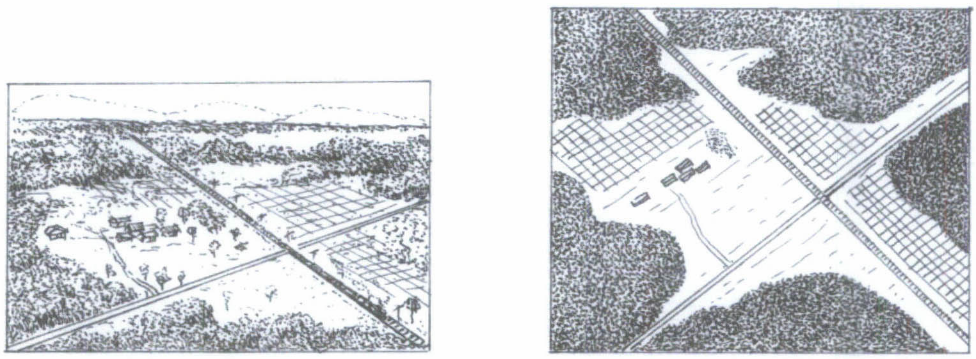
Once a species population within a forest fragment becomes extirpated, re-colonization by migration of founder individuals from other forest areas becomes difficult or impossible, due to inhospitable terrain (*e.g.* agricultural or urban development) between fragments. Few forest animal species migrate across large non-forested areas (except some bats and birds). Consequently, large animal-dispersed seeds are rarely transported between forest fragments.

Four Stages of Forest Fragmentation

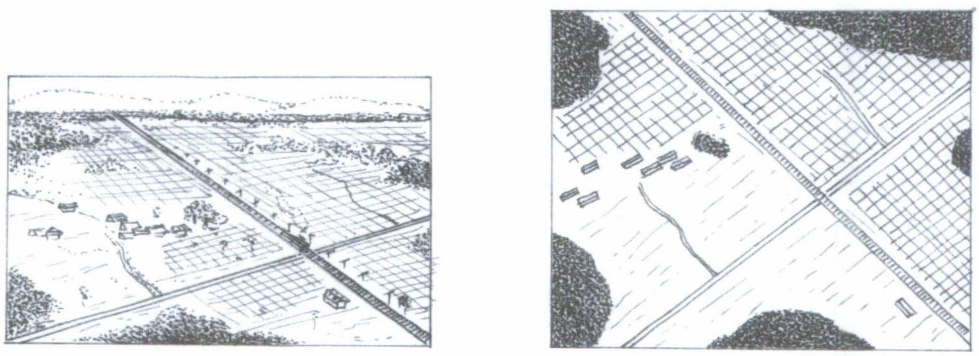
DISSECTION
Roads, railways, power lines etc. cut into a large expanse of forest.



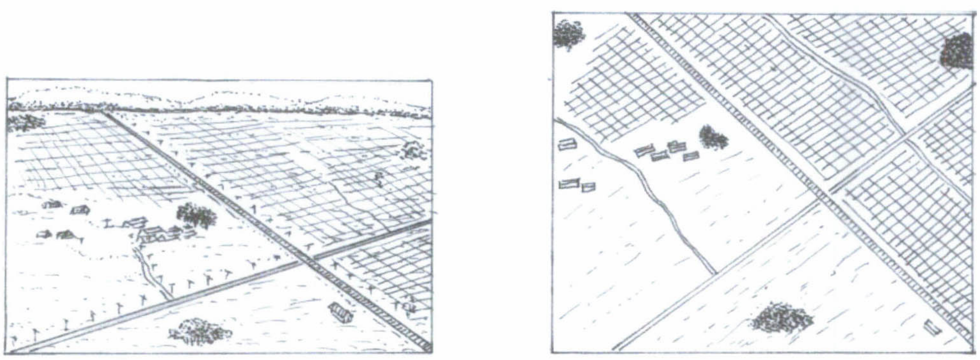
PERFORATION
Holes develop in the forest as settlers exploit the land along the lines of communication.



FRAGMENTATION
The gaps become larger than remaining forest.



ATTRITION
Isolated forest remnants are gradually eroded by edge effects.



Tiny forest fragments can support only very small populations of animals, which are highly vulnerable to extirpation. Once gone, species cannot return, since migration between forest patches is hindered by vast areas of agricultural land or dangerous barriers such as roads. Planting wildlife corridors to re-link forest fragments can overcome some of these problems and help create viable wildlife populations in a fragmented landscape.

What is a wildlife corridor?

Reconnecting small forest fragments to larger forest areas, by planting framework tree species to form "wildlife corridors", can reverse the damaging effects of fragmentation. Such corridors can provide wild animals with the security needed to migrate from one forest patch to another. Genetic mixing recommences and, if a species population becomes extirpated from one forest patch, it can be re-founded by immigration of individuals from another forest patch along the corridor. Wildlife corridors can also help re-establish natural routes followed by migratory species. However, they are only effective where hunting does not occur or can be efficiently prevented. Otherwise wildlife corridors become shooting galleries – drawing wildlife out from the safety of conservation areas and exposing them to danger.

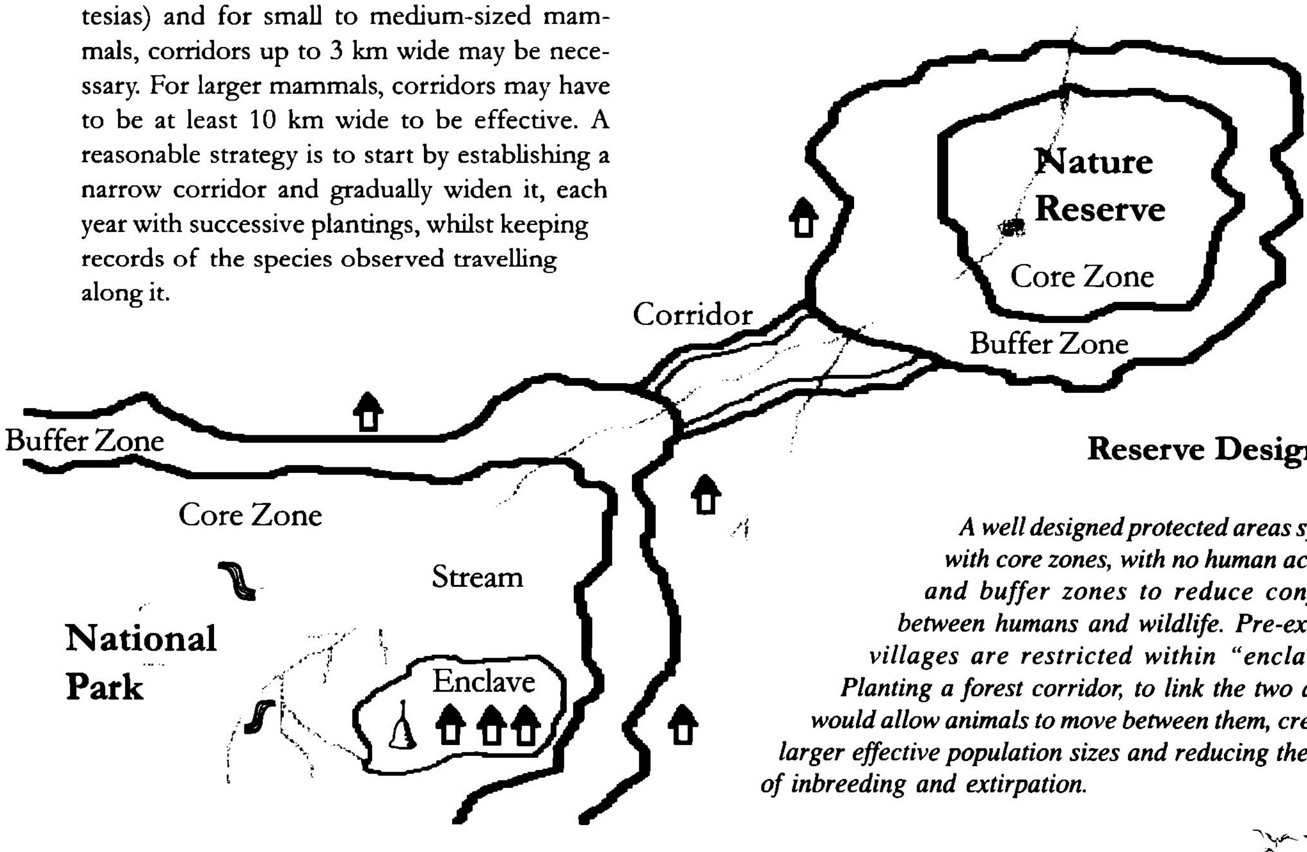
How wide should a corridor be?

This depends on the animals likely to use it. For insects and some small bird species, a line of trees a few metres wide may be sufficient to allow them to move from one forest fragment to another. For birds of the forest floor and undergrowth, however, (e.g. babblers or tesias) and for small to medium-sized mammals, corridors up to 3 km wide may be necessary. For larger mammals, corridors may have to be at least 10 km wide to be effective. A reasonable strategy is to start by establishing a narrow corridor and gradually widen it, each year with successive plantings, whilst keeping records of the species observed travelling along it.

Can tree planting protect water courses?

Yes. Tree planting in upper watersheds, particularly around springs, can help improve the regularity of water supplies and water quality. Although trees do remove water from the soil, by transpiration through their leaves, they more than make up for it by adding organic matter to the soil through leaf litter production. Over time, organic matter increases the water-holding capacity of the soil, so that it can absorb more water during the rainy season and release it during the dry season. In this way, forest restoration can convert seasonally-dry streams into permanently flowing ones.

Planting along stream banks creates riparian habitats that are essential for those specialized species (from dragonflies to otters), which live in or beside sheltered streams. Such habitats also serve as essential refuges for many other, not so specialized, animal species during the dry season, when neighbouring habitats dry out or burn. Riparian tree-planting also prevent stream bank erosion and the clogging of stream channels with silt. This reduces the risk of streams bursting their banks during monsoon deluges, resulting in flash floods.



Reserve Design

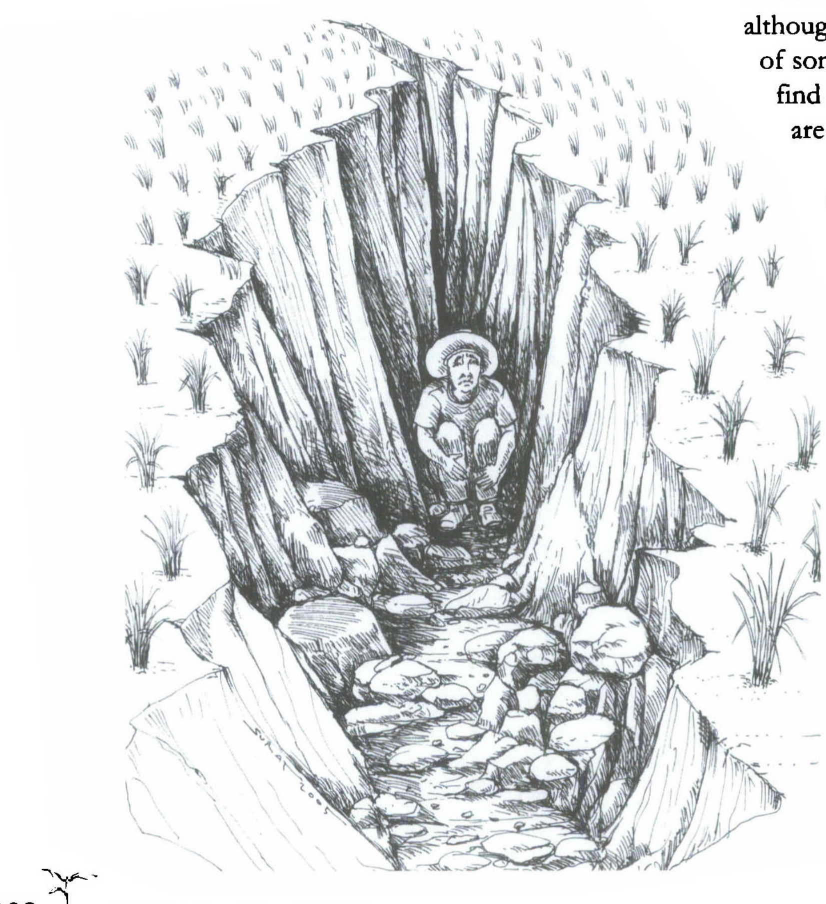
A well designed protected areas system with core zones, with no human activity, and buffer zones to reduce conflicts between humans and wildlife. Pre-existing villages are restricted within "enclaves". Planting a forest corridor, to link the two areas, would allow animals to move between them, creating larger effective population sizes and reducing the risks of inbreeding and extirpation.

Can tree planting reduce soil erosion and landslides?

Yes. Soil erosion reduces the capacity of a water catchment to store water, leading to floods in the rainy season and droughts in the dry season. Deposition of eroded soil in river channels adds to the risk of flooding. Landslides are an extreme form of soil erosion. They can occur with such suddeness and force that they can compeltely detroy villages, infrastructure and agricultural land and kill many people. Mountainous sites with long, steep, uninterrupted slopes are particularly at risk from soil erosion and landslides.

Tree planting can help reduce the risks of both gradual soil erosion and sudden landslides, because tree roots bind the soil, preventing movement of soil particles. Leaf litter helps to improve soil structure and drainage. It increases the penetration of rainwater into the soil (infiltration) and reduces surface runoff.

Gulley erosion can devastate agricultural land and lead to rural poverty. Forest restoration can help prevent both gulley erosion and landslides.



Most countries have a national watershed classification system, with maps showing the relative risk of soil erosion in any particular site. Ask your local agricultural extension service to consult such maps to determine the extent to which tree planting might help reduce erosion in your locality.

Should framework tree species be planted on other sites?

In many circumstances, sites that both i) match the criteria discussed above and ii) are available for forest restoration, may not be present. This may be due to social and legal constraints, including land tenure issues, the need for agricultural land and lack of accessibility. So, is it worth carrying out forest restoration on sites with lower conservation value than those described above?

The answer is "probably yes". Even sites, which are distant from existing forest, can still be planted with framework tree species to good effect. Biodiversity recovery in such sites may occur more slowly and not proceed as far as in sites closer to intact forest. However, more mobile wildlife, such as birds and bats may colonise isolated forest restoration plantings, although large mammals and the largest seeds of some climax forest tree species may never find their way back to such sites unless they are deliberately re-introduced.

One of the main advantages of establishing isolated forest restoration plantings is that they act as "nuclei", from which natural forest regeneration can spread across degraded landscapes, as their seeds are gradually dispersed out into neighbouring areas. They also provide a seed source for future forest restoration tree nurseries in the vicinity.

However, isolated forest restoration plantings are particularly vulnerable to edge effects and the other problems described above for forest fragments, so intensive management is necessary to prevent such problems.

Box 7.1 - Forest Landscape Restoration

What is it?

When planning forest restoration, it is important to consider planting sites as one of many components of the wider landscape, having ecological and socio-economic interactions with agricultural land, natural forest, plantations, water courses, villages, infrastructure and so on.

The World Wide Fund for Nature (WWF) and IUCN-The World Conservation Union have proposed 'Forest Landscape Restoration' (FLR), as an all-encompassing, landscape management concept that aims to "regain ecological integrity and enhance human well-being in deforested or degraded forest landscapes". With the participation of *all* stake-holders, FLR combines several existing development, conservation and natural resource management principles to restore both the quality and quantity of forest, in degraded forest landscapes, to benefit both people and nature.

A "landscape" is defined as a contiguous area of land, intermediate in size between a "site" and an "ecoregion", with distinct ecological and socio-economic characteristics, which distinguish it from neighbouring "landscapes". A forest landscape is defined as "degraded" when, because of forest loss or degradation, it is no longer able to maintain an adequate supply of forest products or ecological services for human well-being, ecosystem functioning and biodiversity conservation.

To conserve biodiversity, FLR recognizes the need to protect and manage remaining forest. Preventing forest fragmentation is seen as critically important to maintain biodiversity. However, FLR acknowledges that forest protection measures, in isolation, will not completely prevent further forest fragmentation and biodiversity loss. Forest restoration is, therefore, acknowledged as an important component of FLR, but one which must provide benefits to people, as well as to wildlife.

In short, FLR is designed to integrate biodiversity conservation with local people's livelihoods at the landscape level. Communities play a critical role in shaping the landscape and, together with wildlife, they must gain significant benefits from forest resources, to provide the necessary motivation to encourage them to take an active role in forest conservation and restoration.

What can it achieve?

By working closely with local communities, through consultation, training and information exchange, FLR should:

- Restore environmental functions – including water, biodiversity and soil stability – by tree planting, ANR or natural regeneration.
- Provide utilitarian benefits to local communities, including forest products, clean water and flood prevention.
- Protect biodiversity and the health of nearby forests.
- Balance land-use trade-offs at the landscape level.
- Keep future land-use options open.
- Adapt to changes in land-use and ecosystem dynamics.
- Reverse the threat of further deforestation.

FORRU-CMU as an example

FORRU's work with local communities provides an excellent example of FLR in practise. In the multipurpose landscape, surrounding the village of Mae Sa Mai, in Doi Suthep-Pui National Park, FORRU-CMU is working with the community to restore forest in the upper watershed to:

- Restore natural forest ecosystems for wildlife conservation.
- Regulate water supplies and water quality, thus contributing to the needs of both the Mae Sa Mai community and downstream communities.
- Provide attractions and stimulus for development of an ecotourism business at Ban Mae Sa Mai and thus generate income.
- Provide encouragement and support for villagers to concentrate agriculture on the development of high-yielding lychee orchards on the more productive and less ecologically sensitive lower slopes.

Who owns the site?

When trying to carry out conservation activities, the last thing you want is a land dispute. When planting on public land, make sure that you get written permission to plant trees, including a map, from the relevant authorities. Most public authorities welcome help with tree planting from community groups and NGO's, but obtaining written permission can take a long time, so start discussions at least a year before the intended planting date. Ensure that all the relevant officials are fully involved in all stages of project planning and implementation. It is important that everyone involved understands that planting trees does not constitute a legal claim to the land.

If planting on private land, make sure that the landowner (and his/her heirs) are fully committed to maintaining the area as forest. Tree planting considerably increases the value of private property, so private landowners should fully cover the costs of tree planting.

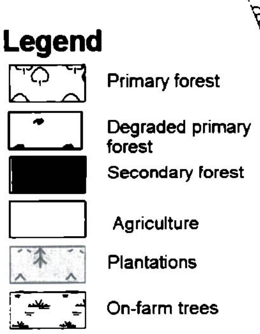
What should be the size and shape of planted plots?

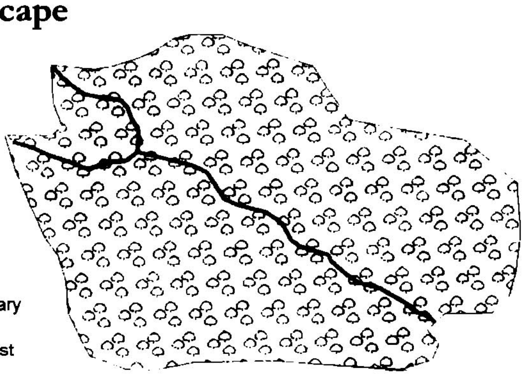
The size of plots planted each year depends on the labour available for weeding and caring for the planted trees during the first two years after planting. This calculation is explained in Part 8.

Bearing in mind "edge effects", already explained, the shape of the planting plot should have a minimal edge:area ratio. This makes a circle the ideal theoretical shape for plots, but it is not a practical shape to lay out on a large scale. As a rough rule, try to make the length and width of planted plots approximately equal and do not plant trees in long, narrow plots, unless your objective is to establish a riparian strip or a wildlife corridor joining two forest patches.

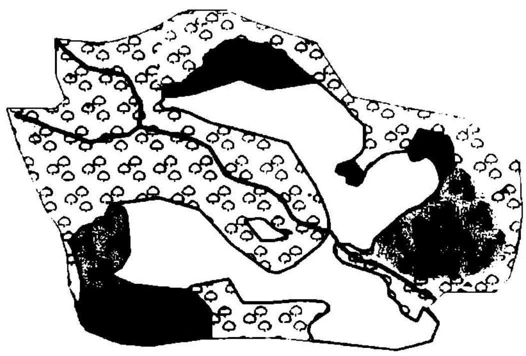
Biodiversity recovery will occur more rapidly if framework forest restoration plots are located adjacent to or nearby existing undisturbed forest.

Forest Landscape Restoration





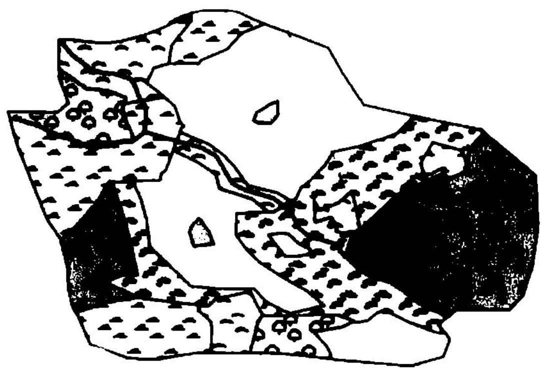
Original landscape, covered with primary forest.



Modified landscape - although land-use patterns have changed, the full range of forest products and ecological functions remain.

Source: Maginnis and Jackson (2002).

Degraded landscape - diminished tree cover has reduced supply of forest products and disrupted ecological functioning of the landscape.



Restored landscape - FLR aims to recover supply of forest products and provision of ecological services at the landscape level.

How do I survey a potential planting site?

All stakeholders (Part 8, Section 2) in a forest restoration project should participate in a survey of the proposed planting site, since it stimulates discussion of a wide range of issues that may affect project planning and implementation, including land rights, labour inputs *etc.* It also helps to build a consensus for the aims of the tree planting program and encourages long-term commitment.

A topographic map, showing forest cover, a compass and a camera are needed to carry out a site survey. It is also useful if a geographical positioning system device (GPS) can be borrowed, perhaps from a local education establishment.

Start with the topographic map (p113, A). Look at the contours to determine the elevation of the site. Look-up the elevation ranges of the framework tree species that are being considered for planting (Part 9) to make sure that they can grow at the elevation of the site. Next, use the contours and the map scale to determine the average site steepness. This will help to determine the risk of soil erosion (B) and how easy it will be to work on the site. Also consider access to the site (C). Look for roads or tracks. How far away from access points will trees and planting materials have to be carried on foot? Remember that planting and tree care take place mostly in the rainy season so, in the field, inspect the condition of access routes to determine if 4WD vehicles, elephants or some other form of transport for the trees and the planters may be needed.

On site, look for sources of natural forest regeneration (D). Estimate the density of naturally established trees, saplings or sprouting stumps. The recommended planting density of framework tree species is around 500 trees per rai (3,000 per ha), but this is for sites with no existing trees. The number of trees planted can be reduced to compensate for the density of naturally established trees or sprouting tree stumps, provided such sources of regeneration are protected from harm during site preparation.

Collect foliage specimens from the trees and sprouting stumps and get them identified by a botanist. Local, vernacular plant names are often ambiguous or used inconsistently, so always try to work with scientific names provided by a trained botanist. Common species of naturally established trees can obviously be omitted from the list of framework trees to be planted (see Table 3.1).

Next, turn your attention to weed cover (p 113 E & Part 3, Section 6). If weed cover is sparse, the labour required for plot preparation can be reduced. Short weeds may be dealt with by a single application of the non-residual herbicide, glyphosate (Round-up). Taller weeds must be slashed first. Then herbicide is applied a few weeks later, after they re-sprout (Section 2).

Then, look at the soil. If the soil is compacted, more labour will be needed to dig the planting holes and mulching will be essential to help improve soil structure. If possible, send some soil samples (F) to your local agricultural college or agricultural extension facility for analysis. This will help you determine how much fertilizer may be required to enable the planted trees to overcome any soil nutrient deficiencies that may be present.

Look for evidence of fire (blackened tree stumps *etc.*). This will help to determine what fire-prevention measures may be needed (Section 4). Also, look for signs of cattle. If necessary, discuss how cattle might be excluded from the site (Part 3 Section 6 and Part 4 Section 2).

Take plenty of photos. These will become an invaluable historical record, when assessing the success of the project years later. If you have a GPS (p113, G), use it to record the positions of the corners of the proposed planted plots and mark them with concrete or metal poles. Use string to create a temporary plot boundary.

Conclude the site survey by erecting a sign board (I), illustrated with a map of the location and extent of the plots to be planted. Display contact details of the project organizers, so that any local people, who may not have heard about the project, can offer help or raise objections.

Finally, use the topographic map to locate the nearest patch of natural forest (H) at a similar elevation to the proposed planting site. A visit to the forest will give all stakeholders a clear picture of the goal of forest restoration. Identify the forest type (see Part 2) and the tree species present and then take a fresh look at the list of tree species that you are planning to plant.

Section 2 - Preparing to Plant

When should trees be planted?

In seasonally dry tropical forest areas, the best time to plant trees is early in the rainy season, once rainfall has become regular and reliable. This gives the trees the maximum length of time to grow a root system that penetrates deep enough into the soil to obtain sufficient water during the first dry season after planting to prevent desiccation. In northern Thailand, the optimal planting time is mid-June to mid-July.

When should plots be prepared for tree planting?

Before planting, clear the plots of weeds. If this is done with a slow-acting, systemic herbicide, such as glyphosate (Round-up), start the process at least 6 weeks before the planned planting date (*i.e.* beginning of May in northern Thailand). If weeding is done entirely with hand tools, clear plots of weeds about 1-2 weeks before planting.

What about existing sources of forest regeneration?

First, take steps to protect any existing, naturally-established trees, seedlings, saplings or live tree stumps that may be present. Inspect the plots thoroughly, taking care not to miss smaller tree seedlings that may be obscured by weeds. Place a bamboo pole, painted with a bright colour, next to each plant found and dig out weeds, using a hoe, in a 1.5 m-diameter circle around each. This makes natural sources of forest regeneration more visible to workers, so they avoid damaging them when weeding or planting. It also releases natural seedlings from competition with weeds so that they can grow up beside the planted trees. Impress upon everyone working in the plots the importance of preserving these natural sources of forest regeneration.

Slashing Weeds

With bamboo poles, clearly mark all sources of natural forest regeneration, including seedlings, saplings and live tree stumps. Then, slash the weeds down to ground level, to prepare for herbicide application.

Making a Site Assessment

When surveying a potential planting site, consider steepness and susceptibility to soil erosion (B), accessibility (C), sources of natural forest regeneration (D), weeds (E) and soil conditions (F).Include a survey of the nearest patch of remaining forest (H) in your site assessment and use a topographic map (A) and GPS (G) to record the position of the plot. Finally, erect a signboard (I) to explain the project to all local people.

PLANTING TREES

It is easy to find enthusiastic volunteers to help to plant trees (above). Lay out plots with a compass, light metal poles and string (left).

Protect trees with shade netting during transportation (above). Getting trees and materials to remote sites can be a problem (right).

This is what happens if you do not weed (above). All trees are dead 1 year after planting; choked beneath a dense bracken fern canopy.

The perfectly planted tree, Mae Ow, Lampoon (above).

Slice open plastic bags with a box cutter (above). Try to keep the root ball and medium intact.

Weed around the planted trees and apply fertilizer as needed during the 1st and 2nd rainy seasons after planting (above).

After planting, give the trees a drink (above) - 2-3 litres per tree. Hire a tanker if necessary.

Can herbicide be used to clear plots for planting?

Yes, but first weeds must be slashed down to below knee height. Leave the slashed material in the plots. It will be used as mulch during tree planting and it will minimize soil erosion and protect soil micro-organisms in the mean time. Wait at least 2-3 weeks for the weeds to start to sprout afresh. Then spray the new shoots with glyphosate (Round-up).

How does glyphosate work?

Glyphosate kills all species of green plants. It rapidly breaks down in the soil, so it does not accumulate in the environment like other pesticides such as DDT. The chemical is absorbed through leaves and is translocated to all other parts of the plant, including the roots. Plants die slowly, gradually turning brown over 1-2 weeks.

Since entire plants are killed, weeds must grow back from germinating seeds. This takes much more time than re-sprouting from slashed shoots or root stocks. So, planted trees have about 6-8 weeks, immediately after planting, relatively free from weed competition. During this time, their roots can colonize soil formerly fully occupied by weed roots.

Spraying Herbicide

How should it be applied?

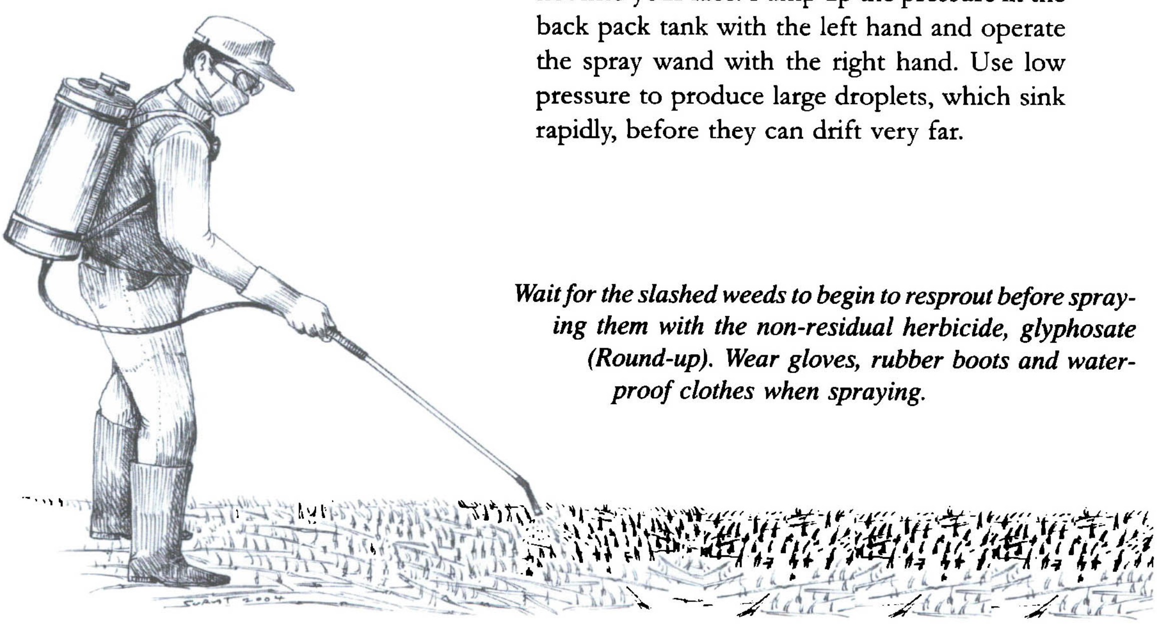
Apply the herbicide on a dry windless day, to prevent drift on to any naturally regenerating tree seedlings. Do not spray if rain is forecast within 24 hours after application. Rain and even dew, within a few hours after spraying, render the chemical ineffective.

Large pumps mounted on pick-up trucks and long hoses, used to spray crops, are often available in agricultural communities. However, we recommend the use of 15-litre backpack tanks with directional spray nozzles, mounted on long wands to apply the glyphosate to clear land for forest restoration. This makes it easier to avoid accidentally spraying naturally established tree seedlings and saplings and prevents over-use of the chemical.

Put on rubber gloves and rubber Wellington boots. Wear a waterproof jacket and trousers. For added safety, a body suit (Dupont Tyvek 100% spun-bonded polyethylene) and mask may be worn, but these are not strictly necessary.

Pour 150 millilitres of the concentrate into a 15-litre-tank backpack sprayer and top up with clean water to the 15-litre mark. You will need 6-8 tank-fulls (900 ml to 1.2 litres of the concentrate) per rai (or 37-50 tank-fulls, 5.6-7.5 litres of concentrate per hectare).

If you accidentally spray the chemical on your skin or in your eyes, wash with large amounts of water and get medical attention. Check the wind direction. Work with the wind behind you, so that the spray is blown forwards; not into your face. Pump up the pressure in the back pack tank with the left hand and operate the spray wand with the right hand. Use low pressure to produce large droplets, which sink rapidly, before they can drift very far.



Wait for the slashed weeds to begin to resprout before spraying them with the non-residual herbicide, glyphosate (Round-up). Wear gloves, rubber boots and waterproof clothes when spraying.

Walk slowly across the site, spraying strips about 3 m wide, by making gentle sweeps from side to side in front of you. Remember where you have been, to avoid spraying the same area twice. Adding a dye to the glyphosate makes it easier to see where you have already sprayed.

Glyphosate kills all plants, including tree seedlings and saplings, so keep a keen look out for them and keep the wand close to the ground. If you accidentally spray a tree seedling or sapling, immediately tear off any leaves where drops of the herbicide have fallen so that the chemical is not absorbed into the plant and transported to the roots.

As soon as possible after spraying, take a shower and wash all clothes worn during spraying. Clean all equipment used (backpacks, boots and gloves) with large quantities of clean water. Make sure that the waste water does not flow into a drinking water supply. Let it seep slowly into a sump pit or into the ground where there is no vegetation, far away from any water course.

Is glyphosate dangerous?

If basic safety instructions are ignored, glyphosate can damage people's health and the environment. So before using it, **read and follow the instructions provided by the supplier**. It has low toxicity to mammals (including humans) but it is toxic to fish, so don't clean any contaminated equipment in streams or lakes. Research is also beginning to show that it may affect soil micro-organisms. However, these minor potential damaging effects of the chemical on the environment must be weighed against the far more damaging long-term consequences of failing to restore forest ecosystems to the environment. Glyphosate is used only once, at the beginning of the forest restoration process. Use of the chemical after trees have been planted, is not recommended.

Isn't it safer to clear plots with hand tools?

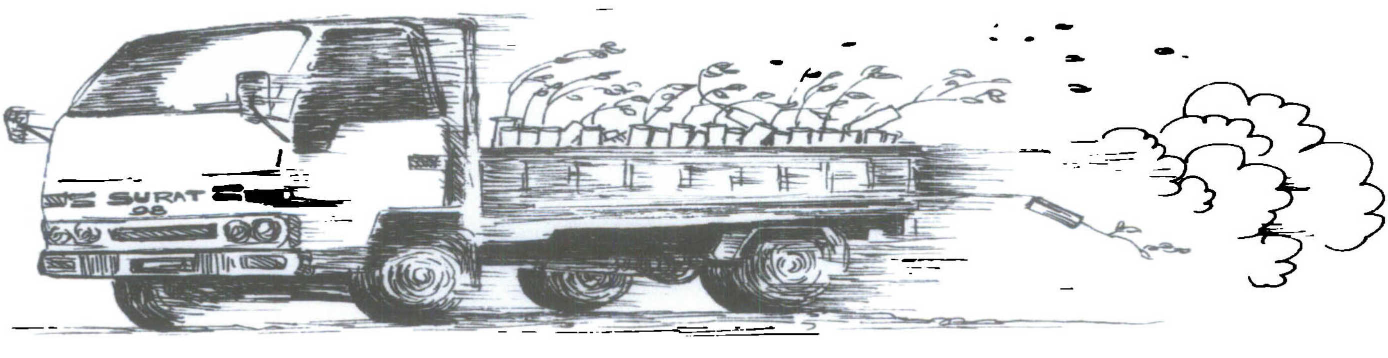
Large numbers of people, wielding machetes and hoes, can cause injuries and damage the environment too, but if you do not want to use a herbicide, there is no alternative. First slash weeds with machetes down to a reasonable height; then dig them out by their roots with a hoe. Make sure a first aid kit is on hand to deal with accidents.

Why dig out the roots?

Merely slashing weeds will only encourage them to re-sprout. As they do so, they absorb more water and nutrients from the soil than if they had never been cut in the first place. This actually intensifies root-competition with the planted trees, rather than reduces it. So, digging out the roots is essential, although the labour

SLOW DOWN !!!

Don't throw away a year's work in the nursery on the journey to the planting site. When transporting saplings, drive with care. Protect them beneath shade netting and don't stack them on top of each other.



required to do so is considerable. Unfortunately, digging out roots also disturbs the soil, increasing the risk of soil erosion. Furthermore, there is a significant risk of accidentally slashing naturally established tree seedlings/saplings.

For these reasons, and to reduce labour costs, we recommend use of glyphosate to clear plots for planting (but NOT for weeding after planting, see Section 4).

Can fire be used to clear plots?

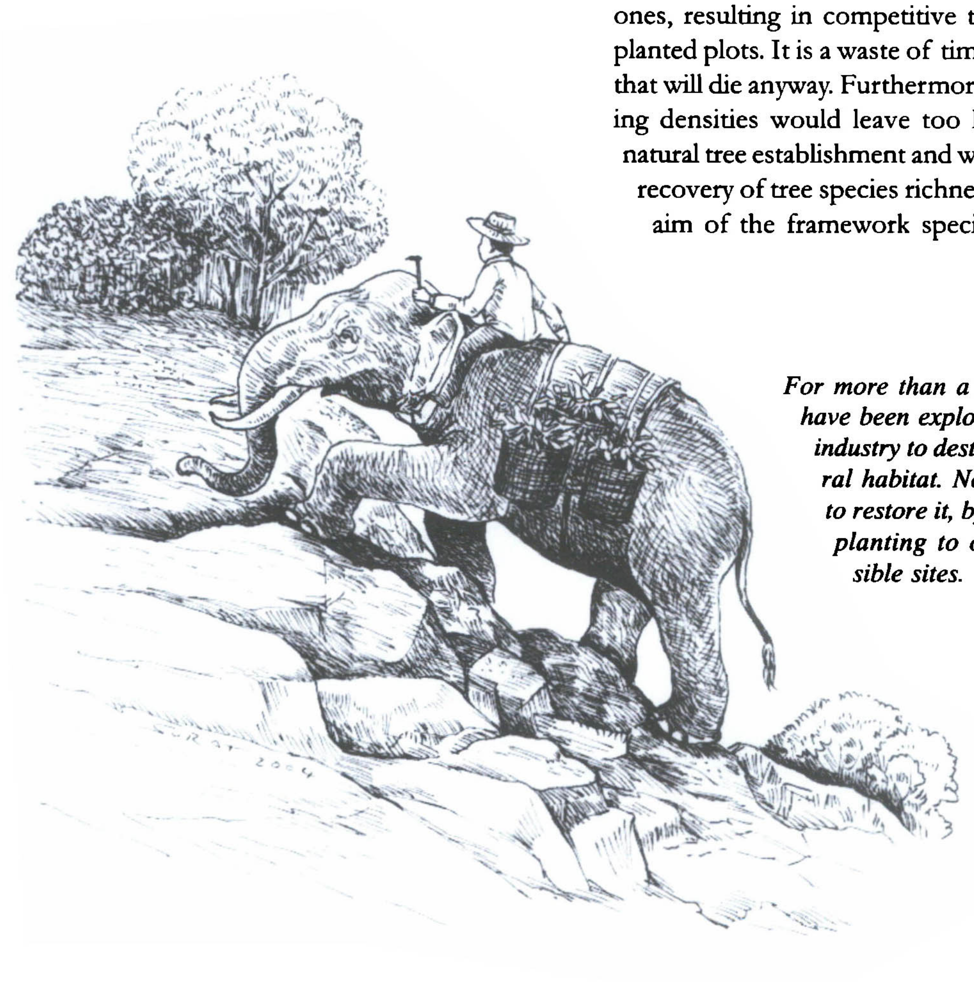
Definitely not. Fire kills any naturally established young trees that may be present, whilst stimulating re-growth of some perennial grasses and other weeds. It also kills beneficial micro-organisms, such as mycorrhizal fungi, and removes the possibility of using slashed weeds as mulch. Organic matter is burnt off and soil nutrients are lost in smoke. There is also a risk that fires, intended to clear a planting plot, may spread out of control to damage nearby forest or crops.

How many saplings should be delivered to the plots?

The final combined density of planted plus naturally established trees should be about 500 trees per rai (or 3,125 per ha), so the required number of saplings delivered to each 1-rai plot should be 500 minus the estimated number of naturally established trees or live tree stumps. This results in an average spacing of about 1.8 m between planted saplings or the same distance between planted saplings and naturally established trees (or live stumps).

This is much closer than the spacing used in most commercial forestry plantations, because the objective is to close canopy, shade out weeds and eliminate the costs of weeding, as quickly as possible. Remember, shade is the most cost effective and environmentally friendly herbicide. Planting fewer trees would mean that weeding would have to be continued for many years and consequently total labour costs to achieve canopy closure would be higher.

If the density of trees were higher than 500 per rai, the slower growing species would not be able to compete with faster growing ones, resulting in competitive thinning of the planted plots. It is a waste of time to plant trees that will die anyway. Furthermore, higher planting densities would leave too little room for natural tree establishment and would thus delay recovery of tree species richness, which is the aim of the framework species method.



For more than a century, elephants have been exploited by the logging industry to destroy their own natural habitat. Now they could help to restore it, by carrying trees for planting to otherwise inaccessible sites.

How many framework tree species should be planted?

Aim to deliver 20-30 species to each plot. Planting more species will accelerate biodiversity recovery, since different wildlife species are attracted to different tree species. However, trying to produce enough saplings of more than 30 species complicates seed collection and nursery management and is not strictly necessary.

How should saplings be transported to the planting plots?

Select only the most vigorous saplings from the nursery, after grading and hardening-off (see Part 6 Sections 6 and 7 respectively). Label the saplings that you intend to include in your monitoring program (see Section 5). Then place all saplings upright in sturdy baskets and transport them to the planting plot, the day before planting.

Even saplings of the highest quality can be damaged by overheating and dehydration during transport to the planting plot. Furthermore, excessive movement can damage fine roots close to the sides of containers. The shoot system may also be damaged, if the containers are not packed carefully in the vehicle.

Some basic precautions can prevent these problems. Water the saplings just before loading them into the vehicle. Make sure containers are packed upright to prevent spillage of potting mix. If plastic bags are used, do not pack them so tightly that they lose their shape. Also, do not stack containers on top of each other, since this will crush shoots and break stems.

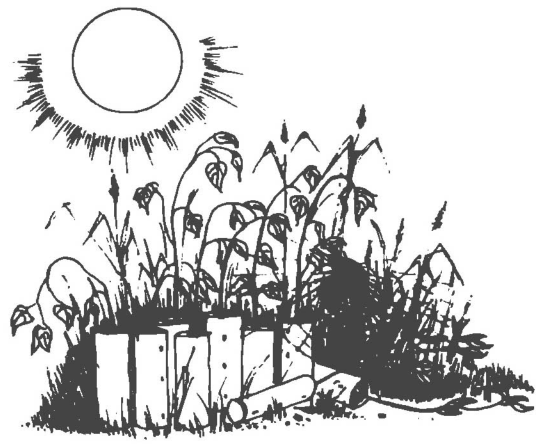
If an open truck is used, cover saplings with a layer of shade netting to protect them from wind damage and dehydration. Drive slowly.

In the plots, place saplings upright beneath any available shade and, if possible, lightly water them again. If you have enough baskets, keep the saplings in baskets, since this makes it easier to carry them around the plot on planting day.

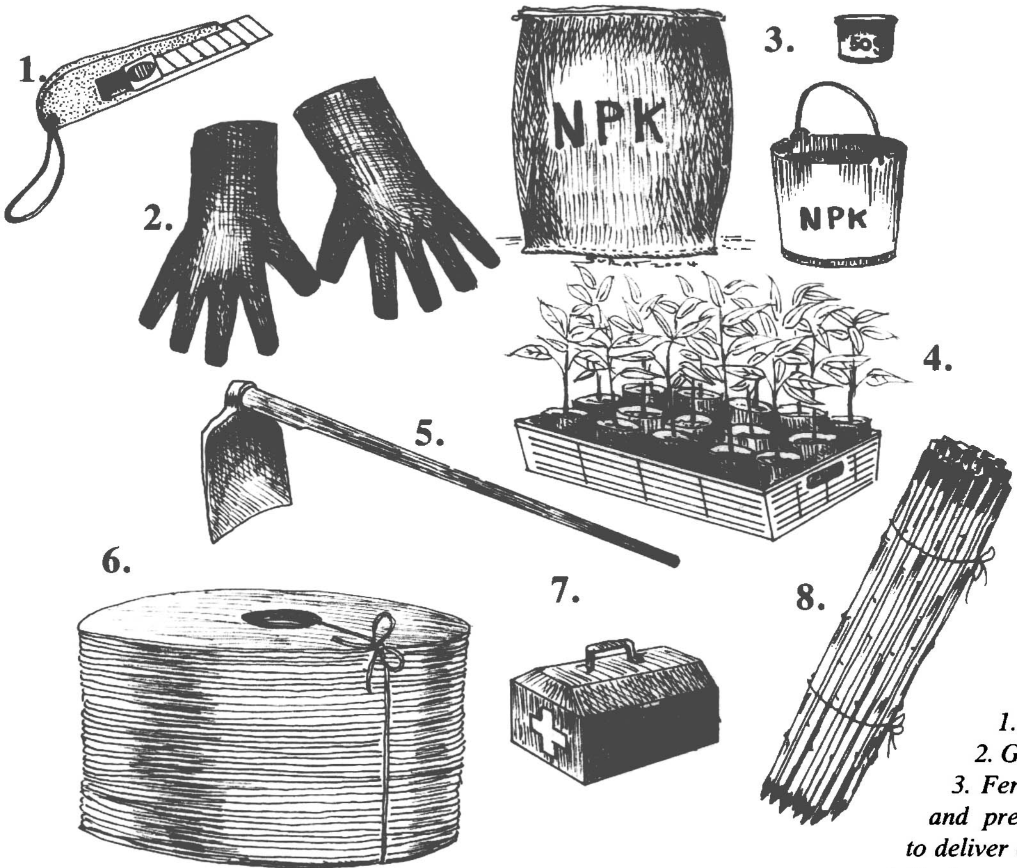
The correct way to carry saplings.

***DO NOT** carry saplings like this. It damages the stems.*

***DO NOT** leave saplings on site like this - exposed to the sun. Find some natural shade or make a temporary shelter with shade netting.*



Essential Tree Planting Equipment



1. Knife
2. Gloves
3. Fertilizer, bucket and pre-measured cups to deliver correct dose
4. Baskets to distribute saplings
5. Hoes for hole-digging
6. Cardboard mulch mats
7. First aid kit
8. Bamboo poles.

What materials should be delivered to the planting site?

Along with the saplings, the day before planting, transport planting materials to the plots. These include a bamboo stake and a cardboard mulch mat for each sapling to be planted and ½ a 50-kg-sack of fertilizer (25 kg) per rai to be planted (or 3¼ sacks (162 kg) per hectare). Protect these materials from rain by covering them in a tarpaulin.

What else needs to be done before the big day?

A few days before the planting event, hold a meeting of all project organizers. Appoint a team leader for each group of planters. Make sure that all team leaders are familiar with the tree planting techniques described in Section 3 and that they know precisely which area each will be responsible for planting. You will need about 8-10 planters per rai to finish the job in one day (50-62 per hectare).

Ask the team leaders to tell their team members to bring gloves, box-cutters (to slash open plastic bags), buckets and cups for fertilizer application and hoes or small shovels (to fill in the planting holes). In addition, team leaders should advise the planters to wear a hat, to protect them from the sun and carry a bottle of water with them. Planters should also be instructed to wear sturdy footware, a long-sleeved shirt and long trousers (to protect themselves from cuts and scratches).

Make a final estimate of the number of people likely to participate in the planting event. Organize enough vehicles to take everyone to the plots and arrange enough food and drink to keep everyone well fed and hydrated. Make contingency plans in case of bad weather. Finally, consider whether the project and the local community might benefit from media coverage of the event and, if so, contact journalists and broadcasters.

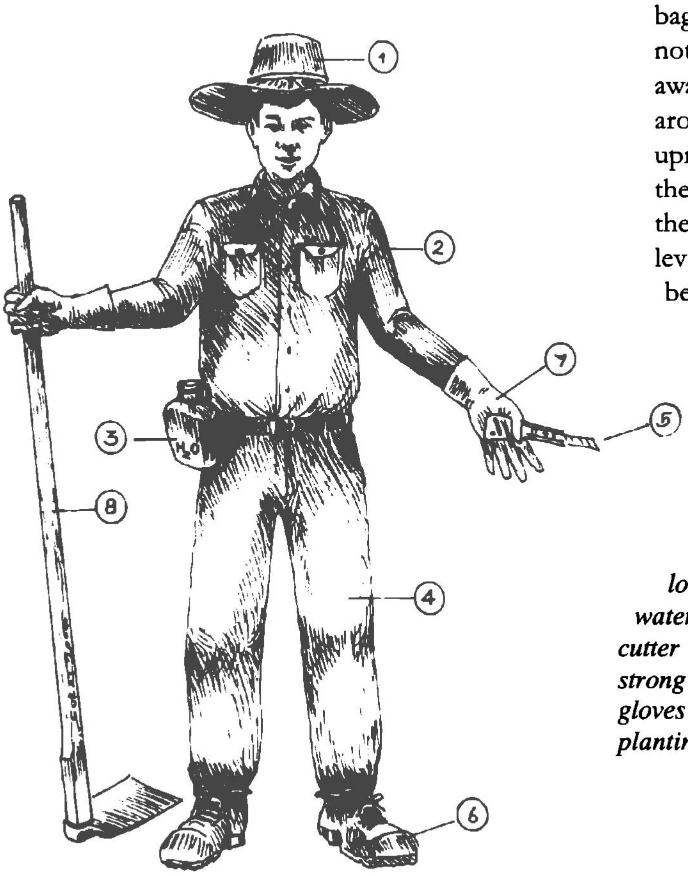
SECTION 3 – THE PLANTING EVENT

Tree planting events do much more than just put trees in the ground. They provide an opportunity for ordinary people to become directly involved in improving their environment. They are also social events, helping to build community spirit. Furthermore, with the help of media coverage, they can portray a positive image of communities as responsible stewards of the natural environment.

Tree planting can also have an educational function. Participants can learn, not only ***how*** to plant trees, but also ***why***. Take time at the beginning of the event to demonstrate the planting techniques to be used and make sure everyone understands the objectives of the forest restoration project. Also, take the opportunity to invite everyone to participate in future follow-up operations, such as weeding, fertilizer application and fire prevention.

How far apart should saplings be planted?

The first step of tree planting is to mark where each tree will be planted with a 50-cm tall bamboo stake. Space the stakes about 1.8 metres apart or the same distance away from naturally established trees or tree stumps. Try not to position the stakes in straight rows. A random arrangement will give a more natural structure to the restored forest. Staking out the plots can either be done on planting day or a few days in advance.



The perfectly prepared planter, with hat (1) to protect him from the sun; long-sleeved shirt (2); plenty of water (3); long trousers (4); a box cutter (5) to slash open plastic bags; strong boots (6) to protect his feet; gloves (7) and a hoe (8) to dig the planting holes.

How should the saplings be planted?

Use baskets to distribute one sapling to each of the stakes. Mix up the species so that saplings of the same species are not planted next to each other.

Beside each bamboo stake, use a hoe to dig a hole, approximately twice the volume of the sapling's container. At the same time, use the hoe to drag away dead weeds in a circle 50-100 cm in diameter around the hole.

If saplings are in plastic bags, slash each bag up one side with a sharp blade, taking care not to damage the root ball inside. Gently peel away the plastic bag. Try to keep the medium around the root ball intact. Place the sapling upright in the hole and pack the space around the root ball with loose soil, making sure that the sapling's root collar is eventually positioned level with the soil surface. If the sapling has been labeled for monitoring, make sure that the label does not become buried.

1. Stake out the site.

2. Dig holes twice the size of the containers

With the palms of your hands, press the soil around the sapling stem to make it firm. This helps to join pores in the nursery medium with those in the plot soil, thus rapidly re-establishing a supply of water and oxygen to sapling's roots.

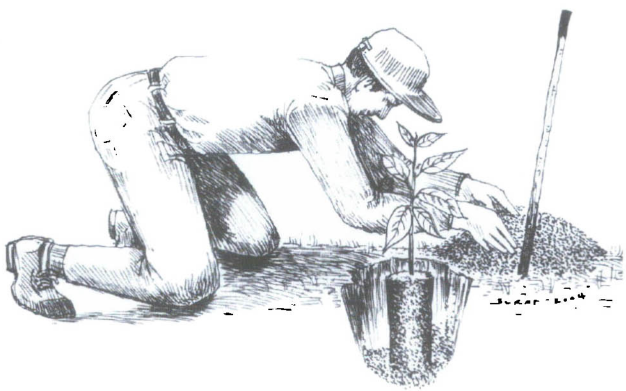
Next, apply 50-100 g fertilizer in a ring on the soil surface, about 10-20 cm away from the sapling stem. If fertilizer contacts the stem, chemical burning can occur. Use pre-measured plastic cups to apply the correct dosage of fertilizer.

Then (optionally) place a cardboard mulch mat, 40-50 cm in diameter around each planted sapling. Anchor the mulch mat in position by piercing it with the bamboo stake. Pile up dead weeds onto the cardboard mulch mat.

At the end of the planting event, if there is a water supply nearby, water each planted sapling with at least 2-3 litres. A water tanker can be hired to deliver water to sites that are accessible by road but distant from natural water supplies. For inaccessible sites with no available water, schedule planting to take place when rain is forecast.

The final task is to remove all plastic bags, spare poles or cardboard mulch mats, and garbage from the site. Team leaders should personally thank all those taking part in the planting. A social event to mark the occasion is also a good way to thank participants and build support for future events.

3. Remove saplings from containers keeping root ball intact.



4. Place sapling in hole and fill in with loose soil.

5. *Firm down soil around the planted sapling.*

6. *Spread fertiliser in a ring 10-20 cm from the stem.*

What kind of fertilizer should be used?

For upland sites, ordinary chemical fertilizer N:P:K 15:15:15 produces good results. Spreading the fertilizer in a ring around the base of the tree is more effective than placing fertilizer in the planting hole, since the nutrients percolate down through the soil as the roots begin to grow into the surrounding soil. On lowland sites, with very poor soils, we have recorded slightly better results using a pelleted organic fertilizer, made from animal waste (Phogaruna Brand). This may be because this type of fertilizer breaks down and is leached from the soil more slowly than chemical fertilizer is. Thus, it delivers nutrients to the tree roots more evenly over a longer period.

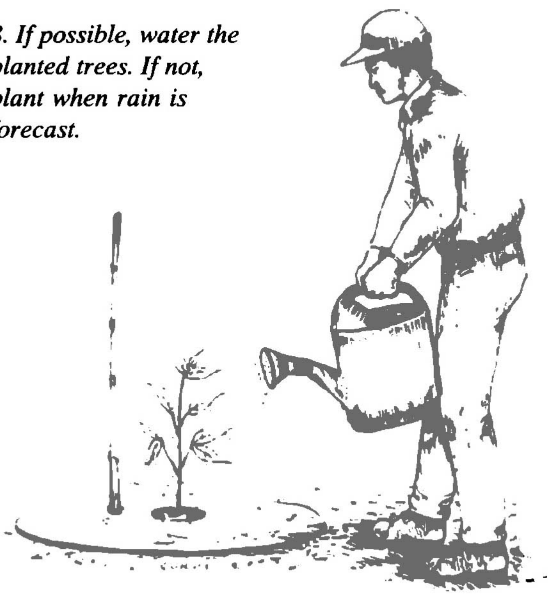
What is the function of a mulch mat?

Mulch mats made of corrugated cardboard can increase the survival and growth of planted saplings, particularly where soils are at risk of drying out immediately after planting. Such mats are particularly recommended when planting deciduous forest trees in the lowlands on lateritic soils.

Most weed seeds are stimulated to germinate by light. Placing mulch mats around planted saplings blocks out light and thus prevents weeds from re-colonizing the ground in the immediate vicinity of planted trees. Furthermore, mulch mats help to keep the soil cool, which reduces evaporation of soil moisture.

7. *Lay cardboard mulch and stake it in place with the bamboo pole.*

8. *If possible, water the planted trees. If not, plant when rain is forecast.*



FIRE

Annually, since 1998, the villagers of Ban Mae Sa Mai have organized an effective fire prevention program. One member of each family joins a work team to cut fire breaks around planted sites in mid-January (right).

During the dry season, each household contributes one member every 11 days to join a 16-person fire team, which spots fires and prevents them spreading to the planted plots (left). So, the workload of fire prevention is shared equally across the community (see Part 8).

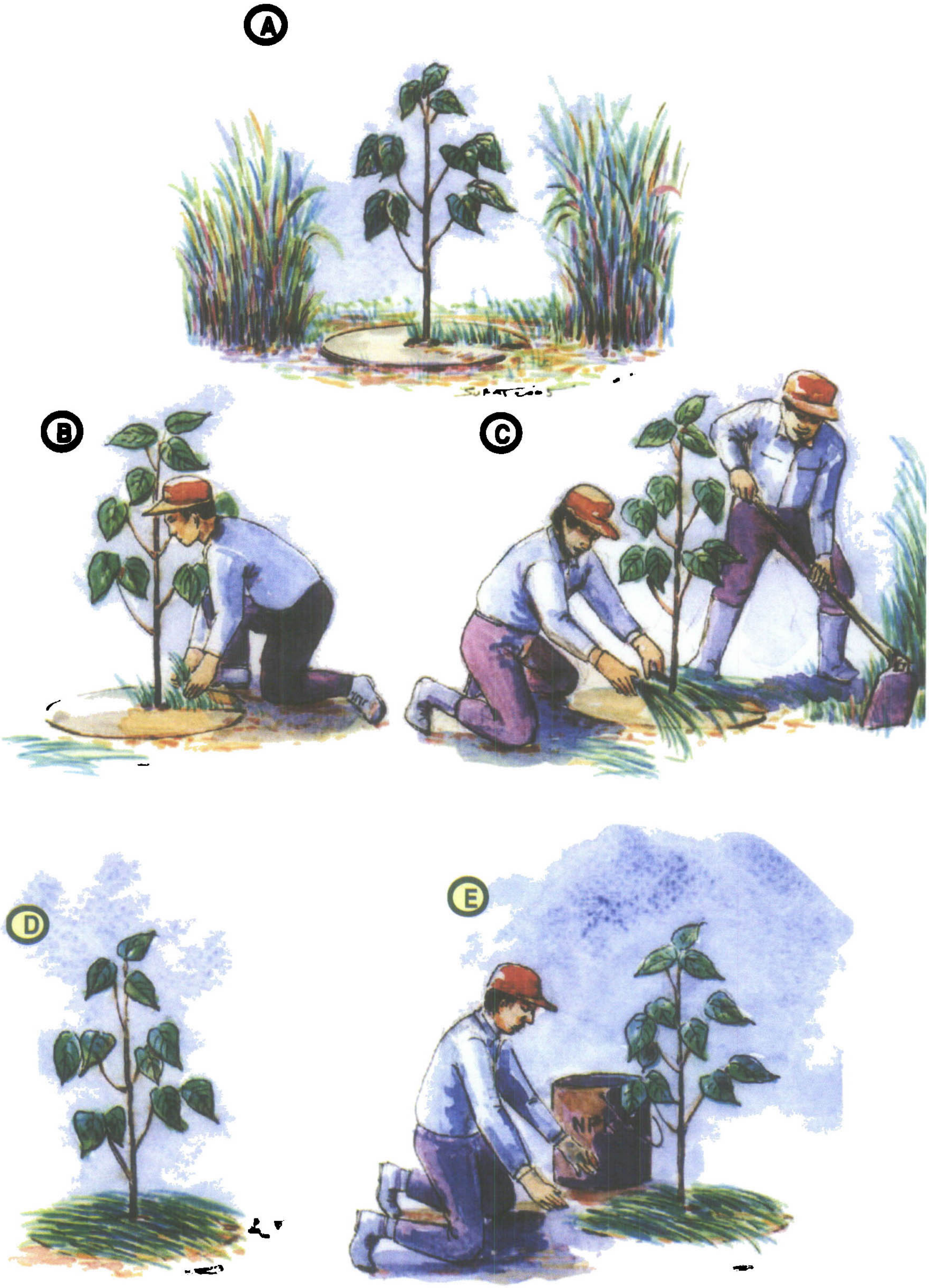
FORRU-CMU and the Forest Department co-sponsor food for the fire team and religeous ceremonies (above).

At the beginning of the fire season, the village spirits are asked to help save the planted trees from burning (left). If the fire prevention program is successful, another ceremony to thank the spirits is performed. A pig is slaughtered for a feast to reward both the spirits and the fire prevention team (above).

Some tree species are more resilient to fire than others. This Prunus cerasoides *tree (right) was burnt 8 months after planting. The original stem is dead but, 3 months after burning, a new stem has sprouted from the root collar.*

Small fire trucks (left) are only practical near roads.

WEEDING IS ESSENTIAL



Weeding is essential to keep planted trees alive during the first two rainy seasons after planting. A cardboard mulch mat can help keep weeds down to a minimum immediately around the tree stem (A). Pull out any weeds growing near the tree base by hand (wear gloves) to avoid damaging the tree roots (B). Try to keep the mulch mat intact. Next, use a hoe to root out weeds in a circle around the mulch mat (C) and lay the uprooted weeds on top of the mulch mat (D). Finally, apply fertilizer (50-100 gm) in a circle around the mulch mat (E).

Soil invertebrates are attracted by the cool, moist conditions beneath the mats. They churn up the soil around planted saplings, improving drainage and aeration.

Cardboard mulch mats should be circular, about 40-50 cm in diameter, with a hole in the middle about 5-10 cm across and a narrow slit, from the circle perimeter to its centre. Open the circle along the slit and place the hole in the middle centrally around the tree stem. Make sure that the cardboard does not touch the stems of the planted tree, since it may abrade them, creating wounds, which can become infected by fungi. Drive a bamboo stake through the mat to keep it in place.

Cardboard mats last one rainy season, gradually rotting down and adding organic matter to the soil. Replacing mats at the beginning of the second rainy season does not seem to result in additional beneficial effects (FORRU-CMU data).

What about polymer gel?

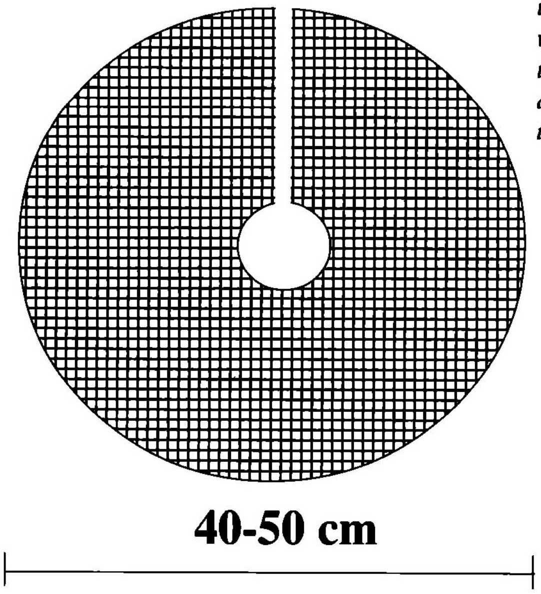
Water-absorbent polymer gel can help keep the roots of planted trees hydrated and reduce transplantation stress. On well-watered highland sites, it is usually unnecessary, but we have found that polymer gel, used in combination with cardboard mulch mats, significantly reduces immediate post-planting mortality amongst deciduous forest trees, when they are planted in dry areas on poor soils.

Polymer gel is widely available from most agricultural supplies shops. Similar products, derived from local materials such as rice and corn starch, are under development. Mix the gel with water, according to the instructions on the packet. Then mix 1-2 litres of hydrated gel with loose soil in each planting hole, just before planting the trees.

What happens after the planting is over?

Most planting events involve large numbers of volunteers. Even with a demonstration of planting techniques at the beginning of the event, it is inevitable that some trees may not be planted properly. So, once the planters have left the site, team leaders should inspect the planted trees and correct errors. Make sure that all the trees are upright, that the soil around them has been properly firmed down and that monitoring labels have not become buried. Look for any saplings that have not been planted and either plant them or return them to the nursery. Refill any holes with no trees in them. Remove any garbage or spare materials that may have been left behind.

Mulch Mats



Mulch mats, cut from recycled corrugated cardboard, are cheap and effective at reducing immediate post-planting mortality of planted trees; particularly on drought-prone sites with poor soils. They suppress weed growth and thus reduce the labour costs of weeding. Fertilizer is applied in a ring around the edge of the mat. Mats last about a year, if care is taken not to disturb them during weeding operations.

Section 4 – Caring for Planted Trees

In deforested sites, planted trees must endure hot, dry, sunny conditions as well as competition from fast-growing weeds. In addition, during the dry season, there is a risk that fire will destroy them. Intensive care of the trees during the first 18 months after planting can significantly reduce these risks. Consequently, although caring for planted trees involves costs and hard work, it is more cost effective than having to replant trees which die. Provided the procedures outlined below are followed and the planted saplings are healthy, vigorous and well hardened-off, the planted forest should become self-sustaining, requiring little or no further maintenance, within 3 years and consequently no subsequent planting should be necessary.

How often is weeding necessary?

The frequency of weeding depends on how fast the weeds grow. On upland sites, weed growth is very rapid during the rainy season. After planting, it is recommended to weed around the planted trees at least 3 times during the rainy season at 4 to 6-week intervals. In the lowlands, weeds usually grow more slowly and more sparsely, so it may be possible to reduce the weeding frequency. Visit the site frequently to observe weed growth. Carry out weeding well before the weeds grow above the height of the planted trees. Do not carry out weeding after the end of November[1]. This allows some weed growth to occur before the onset of the hot, dry season. This can help to shade the planted trees and prevents desiccation during the hottest period of the year. However, it also increases fire risk, so only do this where fire prevention measures are effective. Where fire is particularly likely, try to keep planted plots free of weeds at all times. The labour force required for weeding varies with the weed density but, to complete the job in a single day, 3-4 weeders per rai (20-25/ha) will be needed.

How long must weeding be continued?

Frequent weeding is essential during the first two rainy seasons after planting. It is not usually necessary to weed during the dry season. In the third rainy season after planting, the frequency of weeding can be reduced as the crowns of the planted trees begin to meet and form a forest canopy. By the fourth rainy season, the shade of the forest canopy should be sufficient to prevent weed growth.

How should weeding be done?

Wear a pair of gloves and gently pull out any weeds growing close to tree stems, including any growing through cardboard mulch mats. Try not to disturb the mulch mats too much. Around the mats, use a hoe to dig out weeds by their roots. Lay uprooted weeds around the trees, on top of the mulch mats. This maintains shading of the soil surface, and inhibits germination of weed seeds even as the mulch mat rots away. Try to ensure that uprooted weeds do not touch the tree stems, as this can encourage fungal infection.

Use of machetes or weed whackers close to planted trees is strongly discouraged, to prevent accidentally slashing them, although such tools may be useful to control weeds between the trees. Apply fertilizer immediately after weeding around each tree.

How frequently should fertilizer be applied?

Even on fertile soils, most tree species benefit from application of additional fertilizer during the first two rainy seasons after planting. It enables the trees to grow above the weeds rapidly and shade them out, thus reducing weeding costs. Apply 50-100 g fertilizer, at 4 to 6-week intervals, immediately after weeding, in a ring about 20 cm away from the tree stem. If a cardboard mulch mat has been laid, apply the fertilizer around the edge of the mulch mat.

Chemical fertilizer (N:P:K 15:15:15 Rabbit Brand) is recommended for upland sites, whilst organic pellets (Phogaruna Brand) produces significantly better results on lateritic lowland soils. Application of fertilizer too close to the

[1]except for those tree species listed in Part 9 that benefit from later weeding

stems of planted trees can damage or kill them. Weeding before fertilizer application ensures that the planted trees benefit from the nutrients and not the weeds.

How can fires be prevented?

Fire is an annual hazard during the dry season and can wipe out years of hard work in an instant. Although fires can occur naturally, most are started by humans, so the best way to prevent them is to make sure that everyone in the vicinity supports the tree planting program and understands the need not to start fires anywhere near the planted sites. However, no matter how much effort is put into raising awareness of fire prevention amongst local communities, fire remains the most common cause of failure of forest restoration projects. Although fire suppression units of the Forest Department can help put out fires, they cannot be everywhere, so local, community-based fire control initiatives are often more effective. In addition to public education, fire prevention measures include cutting fire breaks and organizing fire patrols to detect approaching fires and extinguish them before they can spread to planted sites.

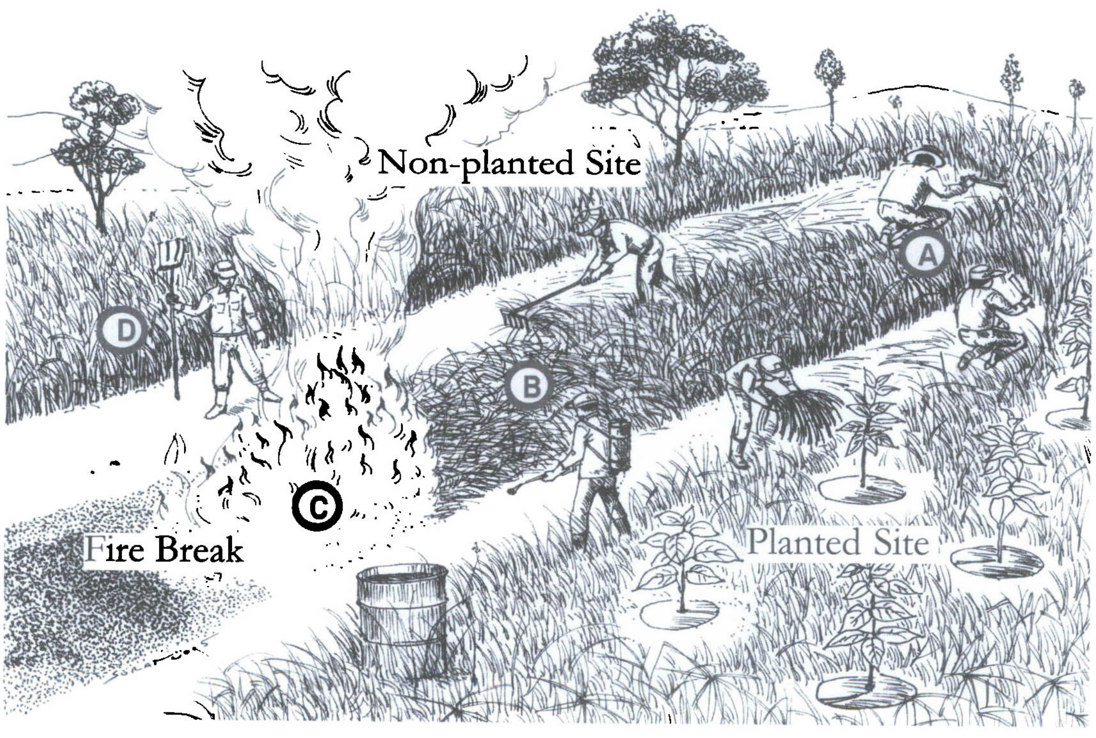
How are fire breaks made?

Fire breaks are strips of land that are cleared of combustible vegetation to prevent the spread of fire. They are effective at blocking moderate, ground-cover burns. More intense fires throw up burning debris, which can be blown across fire breaks to start new fires far away from where the original fire ignited.

Make firebreaks 10 to 15 m wide around planted sites, just before onset of the hot, dry season (mid-January in northern Thailand). The quickest method is to slash all grasses, herbs and shrubs (trees need not be cut) along the two edges of the firebreak. Pile up cut vegetation in the centre of the firebreak. Leave it for a few days to dry out and then burn it. Obviously, using fire to prevent fire can be risky. Make sure plenty of people are available, with beaters and water sprayers, to prevent accidental escape of the fire into surrounding areas. By burning fire breaks just before temperatures soar at the beginning of the hot, dry season, the risk of fire escaping is considerably reduced, since surrounding vegetation retains sufficient moisture not to burn easily. Roads and streams act as natural fire breaks, so there is usually no need to make firebreaks along them.

Making a Firebreak

Use fire to fight fire. (A) Slash two strips of vegetation 10 - 15 m apart. (B) Drag the cut vegetation into the centre. (C) Allow a few days for the cut material to dry out, then burn it off, taking extreme care not to allow the fire to spread outside the firebreak (D).



How can fires be suppressed?

Organize teams of fire watchers to alert local people when fires are spotted so that they can help to extinguish them. Try to involve the whole community in the fire prevention programme, so that each household contributes one family member every few weeks to fire prevention duties. Fire watchers must remain alert night and day from mid-January until mid-April, or until whenever the first rains occur.

Place fire fighting tools and oil drums full of water at strategic places around the planted site. Fire fighting tools include back-pack water tanks with sprayers, beaters to smother the fire, rakes to remove combustible vegetation from the fire front and a first aid kit. Green tree branches can be used as fire beaters. If a permanent stream runs nearby, above the planting site, consider laying pipes into the planted sites. This can greatly increase the efficiency of fire fighting activities, but is very expensive.

Only low intensity, slow moving, ground fires can be controlled with hand tools. More serious fires, especially those that move up into tree crowns, must be controlled by professional fire fighters with aerial support. Be ready to contact local fire fighting authorities if the fire gets out of control.

Most local forest fire control units of the Royal Forest Department are happy to provide training to local people in fire prevention and fire fighting techniques and to supply fire fighting equipment to community-based fire prevention initiatives, so please contact your local forest fire control unit for assistance.

What can be done if planted plots do burn?

All is not lost, especially if some of the framework tree species planted were selected for their fire resilient characteristics. Although no trees are fire-proof, many species can grow back rapidly after having been burnt. Usually this involves re-sprouting from dormant buds around the root collar; "coppicing".

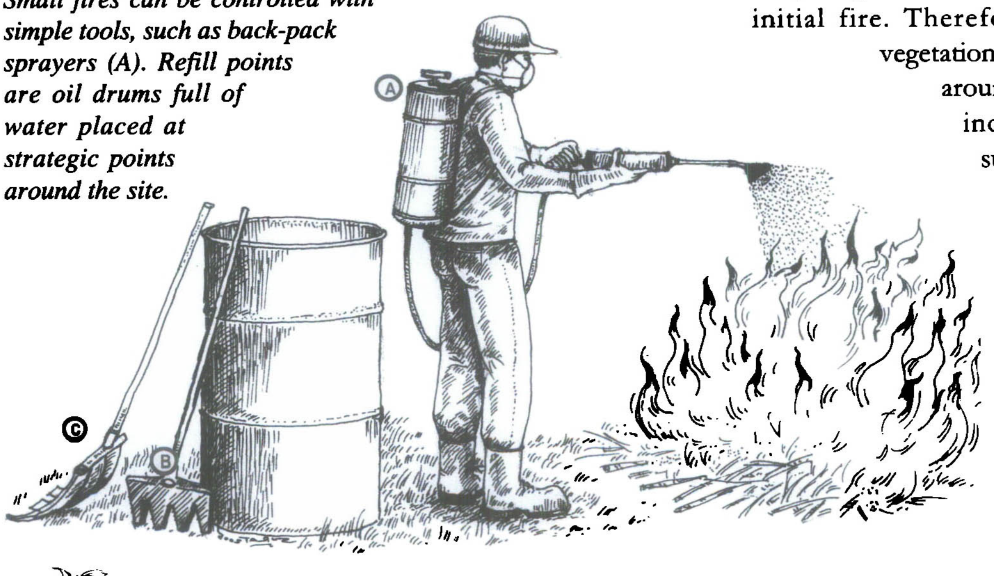
Larger (and older) trees are more likely to re-grow after having been burnt than smaller ones. Most trees with a root collar diameter (RCD) of 5 cm or larger can survive a moderate ground-cover burn. This size is usually reached by the end of the third rainy season after planting for most of the framework species described in Part 9. Younger trees are more vulnerable, but some with RCDs as small as 2 cm may occasionally survive fire.

Framework tree species that are particularly resilient after fire, even within one year after planting, include *Acrocarpus fraxinifolius, Archidendron clypearia, Castanopsis acuminatissima, C. tribuloides, Ficus altissima, F. hispida, F. racemosa, Glochidion kerrii, Gmelina arborea, Heynea trijuga, Hovenia dulcis, Lithocarpus fenestratus, Machilus kurzii, Melia toosendan, Magnolia baillonii, Phyllanthus emblica, Prunus cerasoides, Rhus rhetsoides* and *Sarcosperma arboreum.*

Burnt, dead branches allow entry of pests and pathogens, so cutting them off can speed recovery after burning. Prune dead branches right back, leaving a stump no longer than 5 mm. After fire, the blackened soil surface absorbs more heat, causing more rapid evaporation of soil moisture. This can subsequently kill young trees, which may have survived the initial fire. Therefore, laying mulch (cut vegetation or corrugated cardboard) around young, burnt trees can increase their chances of survival and re-growth.

Fire Control

Small fires can be controlled with simple tools, such as back-pack sprayers (A). Refill points are oil drums full of water placed at strategic points around the site.



Starve the fire of fuel by using a rake (B) to drag away flammable vegetation from approaching flames. Beat out flames with leather beaters (C) or green tree branches.

SECTION 5 – MONITORING FOREST RECOVERY

Why is monitoring necessary?

The purpose of monitoring is to discover if tree planting actually results in the desired effects. For conservation projects, this means finding out whether or not planted trees survive and grow well and whether tree planting accelerates natural forest regeneration and biodiversity recovery, particularly by enhancing the re-establishment of additional (non-planted) tree species. Monitoring can also help to identify problems with species selection, planting techniques and/or the methods used to care for planted trees. It stimulates further experiments to continuously improve restoration projects.

What are control plots and why are they important?

Control plots are as similar as possible to planted plots *e.g.* altitude, slope, aspect, previous land use *etc.,* except that they are not planted with trees. Planted plots are then compared with control plots to determine if tree planting really does result in denser forest, with higher biodiversity than that, which would have developed by natural regeneration. If not, then more resources need not be wasted on a nursery and tree planting. Instead, efforts can be directed towards the ANR techniques described in Part 4. For fire prevention and for effective biodiversity monitoring, particularly of animals, control plots should be placed at least a few hundred metres away from planted plots.

What is the simplest way to carry out monitoring?

The simplest way to assess the effects of tree planting is to take photographs of both planted and control plots, from the same points every few months. Photographs are easier to understand than statistics of survival and growth rates. However, if you want to know which of the planted tree species act effectively as framework trees, then some trees belonging to each of the species planted must be labeled and measured at regular intervals.

How should trees be sampled for monitoring?

When large numbers of trees are planted, it may be impossible to measure them all. The minimum requirement for adequate monitoring is a sample of at least 50 individuals of each species planted. The larger the sample is, the better. Randomly select which trees to include in the sample; label them in the nursery, before transporting them to the planting site. Plant them out randomly across the site, but make sure you can find them again. Place a coloured bamboo pole by each tree to be monitored; rewrite the identification number from the tree label onto the bamboo pole with a weather-proof marker pen and draw a sketch map to help you find the sample trees in the future.

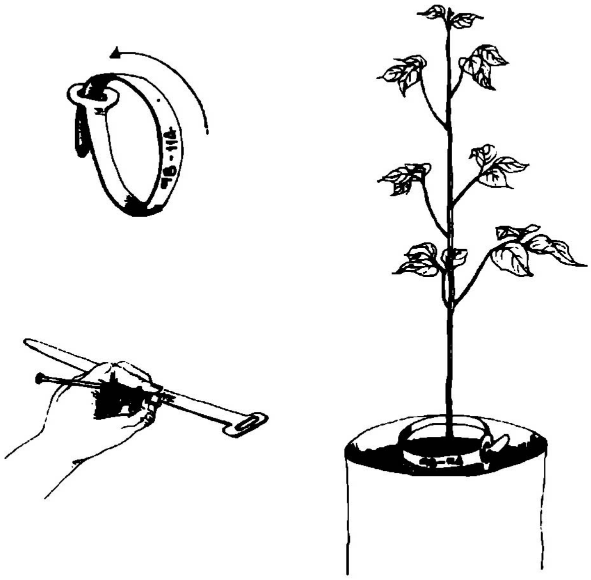
How should planted saplings be labeled?

Soft metal strips, used to bind electrical cables, available from builders' supply stores, make excellent labels for small trees. They can easily be formed into rings around tree stems. Use metal number punchers or a sharp nail to engrave an identification number on each label and bend them into a ring around the stem, above the lowest branch (if present). This will prevent the label from being buried when the tree is planted. Alternatively, drink cans can be cut up to make excellent tree labels. Cut off the top and bottom of the cans and slice the cans' walls into strips. Use a tough ball-point pen to press identification numbers into these soft metal foil strips (on the inside surface). The strips can be formed into loose rings around sapling stems.

Keeping labels in position, on rapidly growing, trees is difficult. As trees grow, their expanding trunks push off labels. If monitoring is carried out frequently, you will be able to re-position or re-place labels, before they are lost.

Once trees have developed a girth of 10 cm or more, more permanent labels can be nailed to their trunks, marking the girth measuring point at 1.3 m above ground (breast height).

Before planting, place metal labels around the tree stems. Make sure they do not get buried during planting. Label numbers could include information on species, year of planting, plot number and tree number. E.g. 98-114 07-3 could mean the 114th individual of species number 98 planted in plot 3 in the year 2007. Keep accurate records of your numbering system.



Use 5-cm-long, galvanized nails, with flat heads. Hammer only about 1/3 of the nail length into the trunk to allow room for tree growth. Metal foil from drinks cans, cut into large squares, so that identification numbers can be read from a distance, make excellent labels for larger trees.

When should measurements be made?

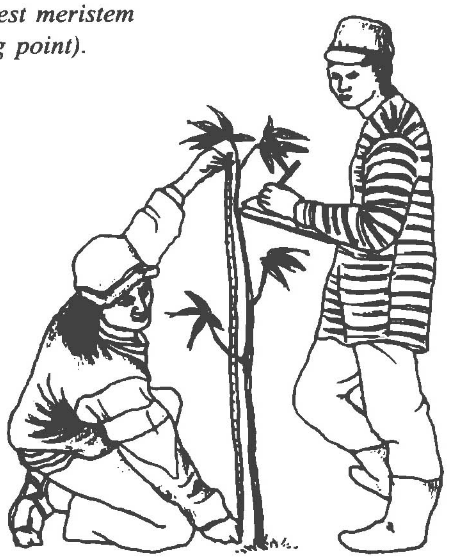
Measure the trees 1-2 weeks after planting, to provide baseline data for growth calculations and to assess immediate mortality, due to transplantation shock and rough handling during the planting process. After that, monitor them annually at the end of each rainy season. Additional monitoring at the end of the dry season can provide more detailed information about when and why trees die.

However, the most important monitoring event is at the end of the second rainy season after planting, when field performance data can be used to quantify how closely each species planted conforms to framework species standards (see Part 5, Section 3). Therefore, even if no other monitoring can be carried out, at least monitor two weeks after planting and at the end of the second rainy season after planting.

To monitor tree performance, work in pairs, with one partner taking measurements and the other recording data on pre-prepared record sheets. One pair can collect data on up to 400 trees per day. Prepare record sheets in advance, including a list of the identification numbers of all labeled trees planted. Take along the sketch maps, made when the labeled trees were planted, to help you find them. In addition, take a copy of the data collected during the previous monitoring session. This can help you sort out tree identification problems, especially for trees that may have lost their labels.

Monitoring Planted Trees

Measure the height of planted trees from the root collar to the highest meristem (growing point).



Measure crown width at the widest point, to assess canopy closure and site "recapture".

What measurements should be made?

Rapid monitoring can involve simple counts of surviving vs. dead trees. More detailed monitoring involves measuring tree height and/ or girth (for calculation of growth rate), crown width and health.

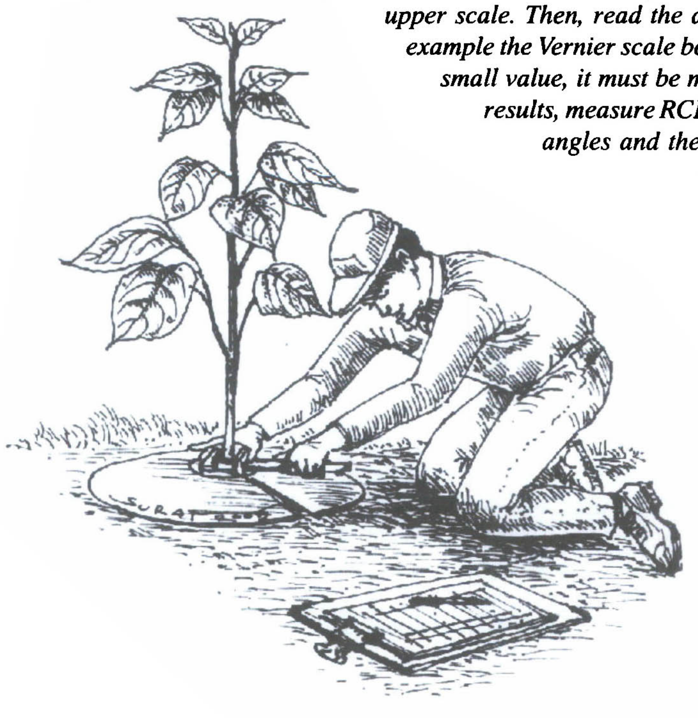
In the first year or two after planting, tree heights can be measured with 1.5-m tape measures mounted on poles. Measure tree height from the root collar to the highest meristem (newest leaf) For taller trees, telescopic measuring poles can be used to measure trees up to 10 m tall. These poles are commercially manufactured but very difficult to obtain in Thailand, so try to make your own. If you want to continue monitoring the trees after they have grown tall, measurements of girth at breast height (GBH) are easier to make and can be used to calculate tree growth rates.

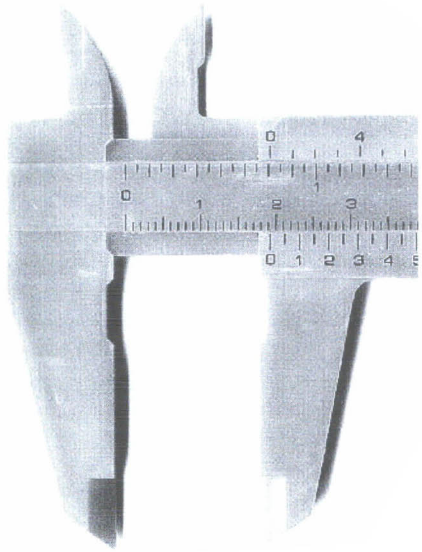
Using height to calculate tree growth can sometimes be unreliable, since shoots can occasionally be damaged or die back, resulting in negative growth rates, even though the tree may be growing vigorously. Consequently, measurements of root collar diameter (RCD) or GBH often provide a more stable assessment of tree growth. For small trees, use callipers with a Vernier scale to measure RCD at the widest point. Once a tree has grown tall enough to develop a GBH of 10 cm, measure both the RCD and the GBH the first time and only GBH thereafter.

Suppression of weed growth (an important framework characteristic) can also be quantified. Measuring crown width and using a scoring system for weed cover can help determine to what extent each tree species contributes to site "recapture". Use tape measures to measure the width of tree crowns at their widest point. Imagine a circle about 1 metre in diameter around the base of each tree. Score 3 if weed cover is dense over the whole circle; 2 if weed cover and leaf litter cover are both moderate; 1 if only a few weeds grow in the circle and 0 for no (or almost no) weeds. Do this before weeding is due to be carried out.

Measuring RCD

Callipers with a Vernier scale are available in most stationary stores.Use them to measure root collar diameter (RCD), at the widest point. At the zero mark on the lower sliding scale, read number of millimetres diameter on the upper scale. For the decimal point, look for the point at which the division marks on the lower scale are exactly alligned with the division marks on the upper scale. Then, read the decimal point off the lower scale. For example the Vernier scale below reads 19.3 mm. Because RCD is a small value, it must be measured with high accuracy. For best results, measure RCD twice by turning the callipers at right angles and then use the average reading.



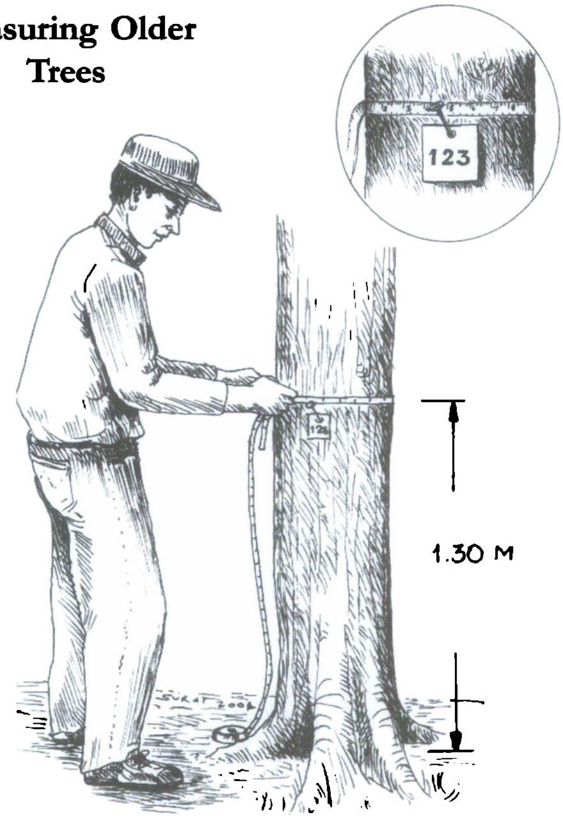


What about tree health?

Recording the health of the planted trees, each time they are inspected, can yield useful information about the vigour and resilience of each species planted to damaging factors such as fire or cattle browsing. For quantitative analysis, assign a simple health score to each tree, but descriptive notes should also be made about any particular health problems observed.

A simple scale of 0 to 3 is usually sufficient to record overall health. Score zero if the tree appears to be dead. Several framework tree species are deciduous, so don't confuse a deciduous tree with no leaves in the dry season with a dead one. Do not stop monitoring trees just because they score zero on one occasion. Many trees, which appear dead above ground, may still have living roots, from which they may subsequently re-sprout new shoots. Score 1 if a tree is nearly dead (few leaves, most leaves discoloured, severe insect damage *etc.*). Score of 2 for trees showing some signs of damage but retaining some healthy foliage. Score 3 for trees in perfect or nearly perfect health.

Measuring Older Trees



Once trees have grown large, subsequent performance monitoring can based on increases in girth at breast height (GBH).

How should data be analysed?[1]

Compare performance among tree species planted to determine which ones function well as framework species, especially at the end of the 2nd rainy season after planting (Part 5, Section 3). To select and perform appropriate statistical tests using the Excell spreadsheet computer program (see Dytham, 1999). Calculate the per cent survival of each species as:

$$\frac{\text{no. labeled trees surviving}}{\text{no. labeled trees planted}} \times 100$$

To show significant differences in survival among species, use a Chi Squared test. Calculate mean tree height and RCD for each species Then, use ANOVA to show significant size differences among the species. In addition, you could calculate relative growth rates (RGR) for each surviving labeled tree:

$$\frac{\ln H\text{ (18 months)} - \ln H\text{ (at planting)}}{\text{No. days between measurements}} \times 36{,}500$$

...where ln H = natural logarithm of tree height (cm). RGR is an estimated annual percentage increase in size. It takes account of differences in the orignal sizes of the trees planted, so it can be used to compare trees that were larger at planting time with those that were smaller. Compare mean values of RGR, among species by ANOVA. The same formula can be used for RCD and crown width.

How should other aspects of forest restoration be monitored?

Inspect planted plots often and record the ages at which each planted tree species starts to flower, fruit or provide other wildlife resources (*e.g.* bird nest sites). Record animals seen (or their signs), especially seed-dispersers. Once canopy closure occurs, survey both planted and control plots for naturally establishing tree seedlings or saplings. Identify and label them and monitor their survival and growth. A similar survey just before planting provides a baseline, against which to assess changes over time.

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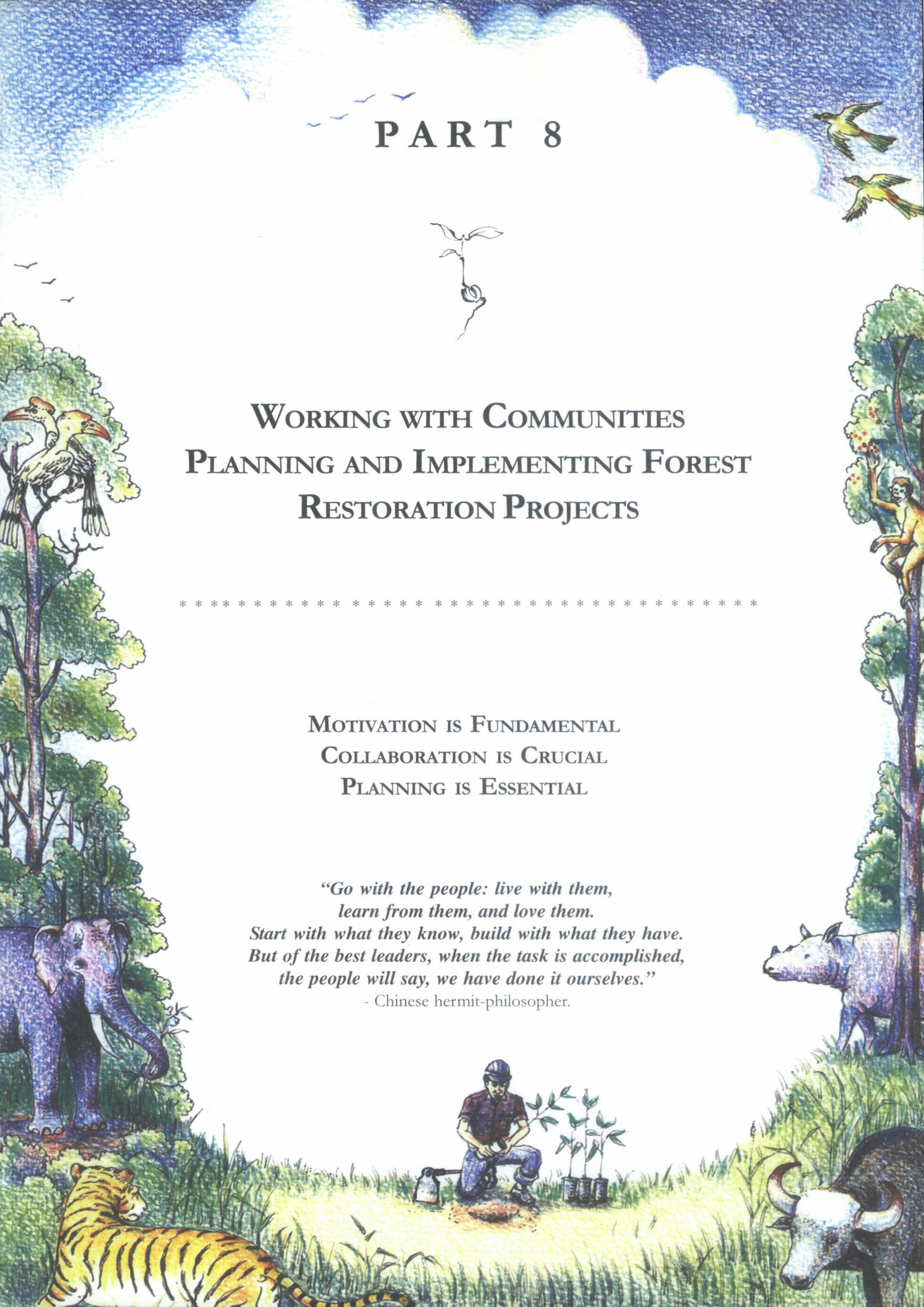
[1]For help with data analysis or to obtain spreadsheets for these calculations, contact FORRU-CMU (page 200).



PART 8

Working with Communities Planning and Implementing Forest Restoration Projects

* *

Motivation is Fundamental
Collaboration is Crucial
Planning is Essential

"Go with the people: live with them,
learn from them, and love them.
Start with what they know, build with what they have.
But of the best leaders, when the task is accomplished,
the people will say, we have done it ourselves."
- Chinese hermit-philosopher.

Restoring Forest - Reviving Culture

At Ban Mae Sa Mai, forest restoration has encouraged a cultural revival within the village. The villagers have adapted traditional ceremonies and initiated new cultural and social activities in response to the growing environmental awareness within their community.

Media interest generates motivation for forest restoration and pride in a community's cultural heritage. Left, village nurseryman, Naeng Thanonworakul peers through the viewfinder of a TV camera, during the filming of a BBC documentary at the village.

Peter Whitbread-Abrutat

Peter Whitbread-Abrutat

The village school children have formed their own bird watching club (above and left). They are trying to discourage bird hunting amongst villagers and are creating a bird sanctuary. FORRU provides technical support to this new group and Britain's Eden Project provided optical equipment and bird books.

At the end of each dry season, the villagers adapt an ancient ceremony to thank the spirits for helping to protect their planted trees from fire. Offerings of pork, whisky and paper money are made.

The villagers revived a traditional ceremony to pay homage to a "holy tree" (above) in one of the last fragments of natural forest in the Mae Sa Valley. In this way, they remind themselves of the importance of forests and the need to restore them.

Villagers, FORRU staff and forestry officials enjoy a shared meal (right) and build better working relationships after thanking the spirits for a fire-free dry season.

Peter Whitbread-Abrutat

Ban Mae Sa Mai lies in a diverse forest landscape (above), which includes remnant natural forest, restored forest, agricultural land, water sources and village infrastructure - a good example of the new concept of forest landscape restoration (FLR), currently being promoted by the International Union for the Conservation of Nature and other organizations (see Box 7.1).

WORKING WITH COMMUNITIES
PLANNING AND IMPLEMENTING FOREST RESTORATION PROJECTS

Whilst it is essential that forest restoration is carried out using the best science available, human aspects are equally important. These include the motivation and resourcefulness of local people, as well as gaining the co-operation of government agencies. Without consideration of these social realities, even the most scientific forest restoration techniques may fail. Although FORRU-CMU is a research and education unit (not a social development organization), its staff has worked closely with local communities to test the feasibility of the restoration techniques developed by the unit. In 1997, FORRU-CMU established a model community tree nursery at Ban Mae Sa Mai, the largest Hmong village in northern Thailand, and worked closely with the village's conservation volunteer group to establish experimental forest restoration plots. FORRU's collaboration with this community, and subsequently with others, has allowed exploration of various social issues, including motivation, work practices and cultural sensitivities. Therefore, in this Part, we share this experience and present some guidelines on the organizational aspects of forest restoration. For a more comprehensive overview of the social aspects of forestry, please refer to the publication list of the Regional Community Forestry Training Centre (RECOFT) (http://www.recoftc.org).

SECTION 1 – MOTIVATION IS FUNDAMENTAL

Economic benefits are the most obvious and measurable sources of motivation for villagers to participate in forest restoration. These include employment, harvesting of forest products, income generated from ecotourism development and so on. However, villagers often regard less tangible benefits, such as improvement of the environment (*e.g.* erosion control, water supplies *etc.*), maintenance of cultural traditions or political gain, as more important reasons to restore forest.

What are the economic motives for forest restoration?

Although some communities may volunteer their labour for forest restoration work, others may take the view that, individuals who work on the project are fairly paid. Therefore, project budgets should include salary payments for those who work full-time on the project (*e.g.* project organizers, nursery managers *etc.*) and daily rates for casual labour (*e.g.* for weeding, fire prevention *etc.*). If forest restoration is considered to be a community activity, in which all community members participate equally, then a contribution to the funding of community projects is appropriate, such as the improvement of school buildings or water systems *etc.* In most projects, both forms of payment are made, since some tasks (*e.g.* planting) involve the whole community, whilst others are carried out by a few individuals (*e.g.* seed collection, nursery work *etc.*). This income can significantly boost the economy of a community. Direct payment is, therefore, a strong motivation for community involvement in forest restoration. It conveys the important message that forest restoration is a valuable activity, which is appreciated by society at large.

Many framework tree species identified by FORRU-CMU yield economic products such as foods, traditional medicines, firewood or timber and some have cultural uses in traditional ceremonies (see Part 9). Non-tree species that colonize restored sites, such as bamboo, honey bees, various fungi *etc.* are also valuable. Provided they are harvested sustainably, such products can provide significant financial incentives for forest restoration.

However, many communities, which could benefit from harvesting forest products, are situated within protected areas, where it is currently illegal (in Thailand) to harvest such products. The Community Forestry Bill (at the time of writing, still under review by the Thailand Government), if made law, would remove restrictions on the harvesting of forest products in areas designated as community forests. However, no forest products could be harvested if there is no forest from which to collect them. Consequently, several communities are restoring forests now in anticipation of having them declared community forest, if or when the new law ever comes into force.

Forest restoration projects can also generate income as ecotourist attractions. Community leaders and NGO officers come to learn from them and academics come to study them. They provide excellent locations for school camps and study sites for student projects. The variety of habitats created attracts both birds and bird watchers. Income can be earned by providing accommodation, food and other facilities for this diverse range of visitors.

Can environmental benefits generate motivation?

Most villagers are aware of the links between deforestation, soil erosion and deterioration of water supplies. Although deforestation in upper watersheds may have few consequences for communities in the immediate vicinity, it often causes siltation of rivers and flooding in communities lower down. These effects may cause conflict between upland and lowland communities, but they can also generate motivation for lowland communities to become involved in forest restoration projects, located many kilometers upstream. However, if watershed protection is to become a strong motivation for forest restoration, a greater understanding of the interdependence of the needs of upland and lowland communities must be developed.

Can cultural considerations encourage forest restoration?

Yes. Forest products often play a vital role in local traditions, whereas the forest, or sacred trees within it, are often regarded as the homes of spirits. Forest loss can, therefore, affect a community's sense of identity and self-esteem. Cultural revival is, therefore, becoming an important motivation for forest restoration.

It is also possible for forest restoration itself to generate new cultural activities. For example, at Ban Mae Sa Mai, Hmong villagers revived a traditional ceremony to ask their guardian spirits for success with their forest restoration projects. At the end of each fire season, pork and whisky are offered to the spirits to thank them for protecting planted trees.

Can forest restoration be carried out for political gain?

Yes. Politics can be the most compelling reason behind a community's participation in forest restoration – particularly the strengthening of land tenure rights. According to Thai law, any communities in protected areas may be evicted on the pretext that local people damage nationally important natural resources. Community involvement in forest restoration, therefore, sends an important message to the authorities - that local people ***can*** be responsible stewards of the environment.

Forest restoration can help to strengthen a community's claim to remain located within a protected area and can help to counter the image that villagers are the primary agents of deforestation.

In addition, ethnic minorities, who may be recent immigrants, can gain public support for citizenship rights, by contributing to national reforestation initiatives. At the local level, forest restoration helps to build better relationships between communities and local authorities.

How can motivation be sustained?

Forest restoration projects require several years of commitment. Motivation can wane as people realize how much effort is involved. Sustained commitment by funding agencies and continuous technical support are both essential to maintain motivation.

Involvement of the community at all stages of the project, from planning to planting and monitoring, is essential to generate a sense of "community stewardship" of the project. Media interest in projects also generates a sense of pride, which helps to maintain motivation at the community level.

Box 8.1

Pride and Politics: motives for participating in forest restoration

At Ban Mae Sa Mai in northern Thailand, Hmong hill tribe villagers formed a partnership with FORRU-CMU to rehabilitate the watershed above their village, by experimenting with the framework tree species method. This project is demonstrating how scientific research and the needs of a community can be combined to create a model system for environmental education. Since Ban Mae Sa Mai is situated in Doi Suthep-Pui National Park, the villagers cannot legally exploit the planted trees economically – so what are their motives?

One of their aims is to improve the image of the village, since hill tribe people are often blamed for deforestation. The residents of Ban Mae Sa Mai aim to change that perception. They display considerable pride as they demonstrate to the project's many visitors how they have created closed canopy forest in three years, where formerly they grew cabbages. Now that some of the upper slopes are no longer farmed, the villagers have intensified their lychee orchards lower down the valley to maintain their income. They also earn extra income from an ecotourism initiative, set up partly to cater for the growing stream of visitors to the project.

The planted areas are contributing to a nationwide project to restore forest on up to 8,000 square kilometres of degraded land to celebrate the Golden Jubilee of Thailand's King Bhumibol Adulyadej. So, this project also allows this ethnic minority to affirm its allegiance to its adopted country. The project's success was also publicly acknowledged by the Forest Department in 2000, with a silver award for tree care presented at the Queen Sirikit National Convention Centre in Bangkok.

Since they live in a national park, the villagers of Ban Mae Sa Mai risk eviction, as Thai law forbids people to live in national parks. Although enforcement of the law in this case is unlikely (since this is the largest Hmong village in northern Thailand), the villagers still feel the need to demonstrate to the authorities that they are capable of re-establishing and caring for forest in a protected area. Therefore, by restoring forest, the villagers re-assert their rights to Thai citizenship and to remain living in the national park.

Another powerful motivation for forest restoration is the preservation of water supplies. Thirty years ago, the village had to relocate from a site higher up the valley to its present location because the village's main water source dried up, due to forest clearance for crop production. Thus, the villagers are acutely aware of the link between forests and water and the importance of restoring forests in watersheds.

The villagers grow framework tree seedlings in their own community nursery and plant them out annually. They weed and apply fertilizer around the planted trees, protect them from fire and monitor their growth. Furthermore, the community also enforces its own regulations to prevent hunting and tree felling in the area, with fines for transgressors.

The village nursery and plots have become vital facilities for education, with frequent school events and workshops being conducted on site. Representatives from many other communities visit the village to find out how they too, can establish their own successful tree planting projects. Thus, the villagers of Ban Mae Sa Mai have converted their former cabbage fields into a classroom for forest restoration.

A Hmong girl pots a tree seedling in Ban Mae Sa Mai's tree nursery. Providing a better future for children is a strong motivation for communities to restore forests.

Section 2 – Collaboration is Crucial

Forest restoration is rarely carried out by a single organization. Community groups, government departments, NGO's, funding agencies and technical advisers all play vital roles. Close collaboration among all these "stakeholder" groups is essential to maximize the benefits for all involved, ensure sustainability and prevent wastage of resources.

Who are the "stakeholders"?

Stakeholders are individuals or groups of people that have any kind of interest in the area of land to be restored. They may also include those who may influence the long-term success of the restoration project, such as technical advisors, funders or government officials.

It is very important to involve all stakeholders in all stages of project planning and implementation. However, it is inevitable that different stakeholders will have different opinions about the eventual use of the restored forest and whose interests will be served by it. They may also disagree about which restoration methods will be most successful. The success of forest restoration programs often depends on resolving these issues early on in the planning process.

Any conflicts amongst stakeholders must be resolved through frequent meetings, at which records are kept for future reference. The purpose of these meetings should be to reach a consensus on a project plan, in which the responsibilities of all stakeholders are clearly defined to prevent confusion and replication of effort.

How can collaboration be encouraged?

Even though different stakeholders may have different interests, common goals can usually be found. It is important to acknowledge the strengths and weaknesses of each of the stakeholders, so that a joint strategy can be devised, whilst allowing each stakeholder group to maintain its own identity. Once the capabilities of each stakeholder group have been identified, their roles can be defined and the tasks of each agreed upon.

This is often a tricky process, which is best carried out by a neutral person or organization that is familiar with the stakeholders, but not seen as authoritarian or gaining any benefit from involvement in the project. The role of the facilitator is to ensure all opinions are discussed, everyone agrees with the aim of the project and that responsibility for the various tasks is accepted by those most able to carry them out.

Collaboration is maintained when all stakeholders are content with the benefits they might receive from the project and believe that their contribution is beneficial to the project's success. When everyone is satisfied that they have had input into project planning, a sense of "community stewardship" of the project is generated (even though this may not mean legal ownership of the land or trees), which helps to maintain essential working relationships amongst the stakeholders.

Planning together - FORRU-CMU staff, forest officials and Ban Mae Sa Mai villagers decide where to establish the first experimental framework species plots in 1996. Nearly a decade later, this collaborative partnership is still going strong.

SECTION 3 – PLANNING IS ESSENTIAL

The project plan defines the objectives of a forest restoration project; where it will be located and how it will be implemented. It is a working document, which allows for changes in the opinions of stakeholders, as new information becomes available, but each updated draft should represent the current consensus of all stakeholders. The act of writing and updating a project plan helps everyone to focus attention on the essential issues of **who** will do what, **when**, **where** and **how** and **how much it will cost** in terms of time, labour and money.

What goes into a project plan?

A project plan must include a clear statement of objectives; a description of the site to be planted; the methods that will be used to restore forest to the site and a schedule of the activities to implement those methods. The plan should also include calculations of labour requirements and the costs of each activity.

Objectives - why?

All activities depend on the project objectives. So, it is important that they are clearly defined and that they represent the consensus of all stakeholders. The objectives section of the plan should state the reasons why forest restoration is being carried out; the expected project outputs (*e.g.* forest products, water, political gains *etc.*) and who will benefit from them.

Site description – where?

A detailed report on the site survey (see Part 7, Section 1) is an essential component of the project plan, so that land tenure issues are properly addressed and everyone understands the extent of the areas to be planted. This section of the plan should include a site sketch map (with GPS or map co-ordinates) and photographs of the initial condition of the site.

Methods – how?

Review the various techniques described in this book and record which ones the stakeholders agree are the most appropriate to achieve the project objectives, considering the initial condition of the site.

Work schedule – when?

An example work schedule is presented on the next page. Once the methods to be used have been agreed upon, they must be converted into a series of tasks, with dates assigned to each. Then, responsibility for carrying out each task can be distributed amongst the various stakeholders. It is a common mistake to underestimate the total time required to implement forest restoration projects. If trees are grown locally from seed, nursery construction and seed collection must begin 18 months to 2 years before the first planned planting date.

How many people will be needed - who?

Forest restoration is hard work but, as with any arduous but worthwhile task, sharing the work amongst many people not only lightens the load, but also turns a chore into an enjoyable social event. The amount of labour available is the critical factor that determines the maximum area that can be planted each year.

Grand schemes, with ambitious aims to instantly replant vast areas, often fail because they do not take into account the limited capacity of local people to carry out weeding and fire prevention. It is better to plant small areas (which can be adequately cared for by the locally available labour force) annually, over many years, than to plant large areas in a single step and have the planted trees die of neglect.

Tree planting and aftercare, especially fire prevention, are usually organized as community activities *i.e.* the village committee requests that each family in the village provides one adult to work on each day that a scheduled task is carried out. The maximum area that can be planted each year, therefore, depends on the number

Table 8.1 An example work schedule. Once dates have been set for the tasks, add a column to record who will be responsible for organizing each one.

Time relative to first planting event	Action
2 years before	Stakeholder consensus reached. First draft of project plan. Start nursery establishment (Part 6, Section 1).
18 months before	Start seed collection and seedling production (Part 6, Section 2).
12-18 months before	Finalize plots to be planted in 1st year (Part 7, Section 1).
6 months before	Check number of saplings ready for planting. Supplement with seedlings of local origin from other nurseries if necessary.
2 months before	Begin hardening-off (Part 6, Section 7); contact volunteer planters.
6 weeks before	Demarcate plot boundaries; mark natural sources of regeneration and slash weeds down to ground level (Part 7, Section 2).
1 month before	Label saplings to be monitored; prepare planting materials; apply herbicide (glyphosate) to re-sprouting weeds (Part 7, Section 2).
1 day before	Transport saplings and all planting equipment and materials to planting plots; brief planting team leaders (Part 7, Section 2).
	Planting event - early rainy season (June for northern Thailand) (Part 7, Section 3).
1-2 days after	Check quality of planting; adjust any badly planted saplings and remove any garbage from the planting site.
1-2 weeks after	Collect baseline data on trees to be monitored (health score, *etc.*) (Part 7, Section 5).
During first rainy season after planting	Weeding and fertilizer application every 4-6 weeks, as required (Part 7, Section 4).
End first rainy season	Monitor growth and survival of planted trees (Part 7, Section 5).
Start first dry season	Cut fire breaks; organize fire patrols. (Part 7, Section 4).
End of dry season	Monitor growth and survival of planted trees (Part 7, Section 5). Weeding and fertilizer application (Part 7, Section 4). Assess the need for maintenance planting.
1 year after	Maintenance planting - if needed.
2nd rainy season after	Continue weeding, fertilizer application, as required.
End 2nd rainy season after	Monitor growth and survival of planted trees (monitoring at this time provides the best prediction of likely overall success).
Subsequent years	Continue weeding in rainy season as needed, until canopy closure is complete. Monitor recovery of biodiversity and continue monitoring planted trees as needed (Part 7, Sections 4-5).

of participating households. As community size increases, an "economy of scale" comes into effect, meaning that a larger area can be planted with fewer days labour input from each household.

The labour needed for most tasks (except fire prevention) is area-dependent (*i.e.* the greater the area planted, the more days labour are needed). To prevent fires, teams of 8 or so fire watchers are required to be on duty day and night, regardless of the size of the planted plots (from 1 to about 50 rai). For small areas, fire prevention uses more labour than all other activities combined. In larger communities, the sharing of fire prevention duties amongst larger numbers of households greatly reduces the labour input required per household (see Table 8.3).

AREA-DEPENDENT WORK		Person-days labour per rai		Total person-days labour required for areas of...		
		1st Year Planting	2nd Year Maintenance	10 rai	10 rai	50 rai
Site preparation	4 people/rai[1]	4	0	4	40	200
Planting	8 trees/person per hour over 6-h. 500 trees/rai[2]	10	0	10	100	500
Weeding and fertiliser application	4 people/rai[3] times year[1]	12	12	24	240	1200
Monitoring	2 people/rai (optional?)[3]	4	2	6	12	24
Fire Breaks (2 years)	Depends on edge:area ratio[4]			4	12	28
	Total for area-dependent work>>			48	404	1952
FIRE PREVENTION (AREA INDEPENDENT)		1st Year	2nd Year	1 rai	10 rai	50 rai
Fire lookout team and fire fighting	90 days; 8 people/day caring for op to 50 rai[5]	720	720	1440	1440	1440
		GRAND TOTAL>>		1488	1844	3392

[1] Adjust according to weed density.
[2] Reduce if naturally occuring trees or live stumps are present.
[3] Reduce for larger sites by sampling a few rai only.
[4] Depends on the shape and distribution of the plots
[5] Required both day and night.

Table 8.2. - Estimated person-days labour required for each forest restoration task over two years. All tasks, except fire prevention, are area-dependent. A "rai" is the standard measure of land area in Thailand. It is 40 x 40 m. 1 ha = 6.25 rai.

Table 8.3 - Person-days labour required per household to restore forest to areas from 1 to 50 rai (including fire prevention) over 2 years.

	Number of households in community			
Area planted (rai)	10	50	100	200
1	149	30	15	7
5	165	33	16	8
10	184	37	18	9
25	242	48	24	12
50	339	68	34	17

At the outset of any forest restoration project, stakeholders must be aware of labour commitments both to plant the trees and to care for them until canopy closure occurs, after which no further maintenance is required.

Project planners must also address the crucial issue of whether labour will be donated voluntarily or whether daily rates for casual labour must be paid. If the latter, then labour costs will dominate the budget. From FORRU's experience, if villagers really appreciate the benefits of forest restoration both to individual families as well as to the community, and have strong motivation, they are usually willing to work on a voluntary basis. Because fire prevention generates immediate broad benefits for the whole community, it is the activity most likely to be supported with voluntary labour.

Table 8.2 provides a template to aid calculation of labour requirements during the first two years after planting. After that, labour requirements fall considerably but vary, depending on the extent of canopy closure and weed suppression. Therefore, from the 3rd year onwards, labour for weeding *etc.* must be individually re-assessed, depending on the condition of each planted plot.

If work is declared a community activity, with each household required to provide one person for each activity, the total workload per household declines as the number of households in the community increases. Table 8.3 shows the number of person-days of labour needed from each household for different sizes of areas planted over 2 years.

What are the costs?

Prices for materials and labour depend on local conditions. Here we can only provide a few guidelines to help you to estimate costs:

Nursery costs include i) nursery construction and equipment; ii) consumable materials and iii) salary or daily rates for a nursery manager and helpers.

Construction of a community nursery need not be expensive. Use of locally available materials, such as bamboo, can help keep costs down. A nursery lasts many years. So, construction costs represent only a small fraction of the total costs of tree production.

Reduce tree poduction costs by using local media such as rice husk and home-made compost instead of commercial potting mixes. Although many such materials are essentially "free", don't forget to factor in the labour and transportation costs of collecting them. The only nursery items, for which there is no effective natural substitute, are plastic bags or containers. Plastic bags cannot be used more than once, so the cost of the bag is the largest monetary cost of tree production.

One nursery manager should have overall responsibility for running the nursery and for ensuring that enough high quality trees are produced of enough species by planting time. This may be a full-time or part-time salaried position, depending on the numbers of trees to be produced. Casual labour may be voluntary or daily rates paid as required. Nursery work is seasonal, with the heaviest workload just before planting and lighter workloads at other times of the year.

At current rates[1], a simple community tree nursery, with a capacity to produce 10,000-20,000 saplings per year, can be established for about 15,000-20,000 baht. Sapling production costs average about 2.0-2.5 baht per plant (including materials and labour). Therefore, the cost of the trees required to plant 1 rai is about 1,000 to 1,250 baht[1] (assuming a planting density of 500 trees per rai; =US$162-203 per hectare).

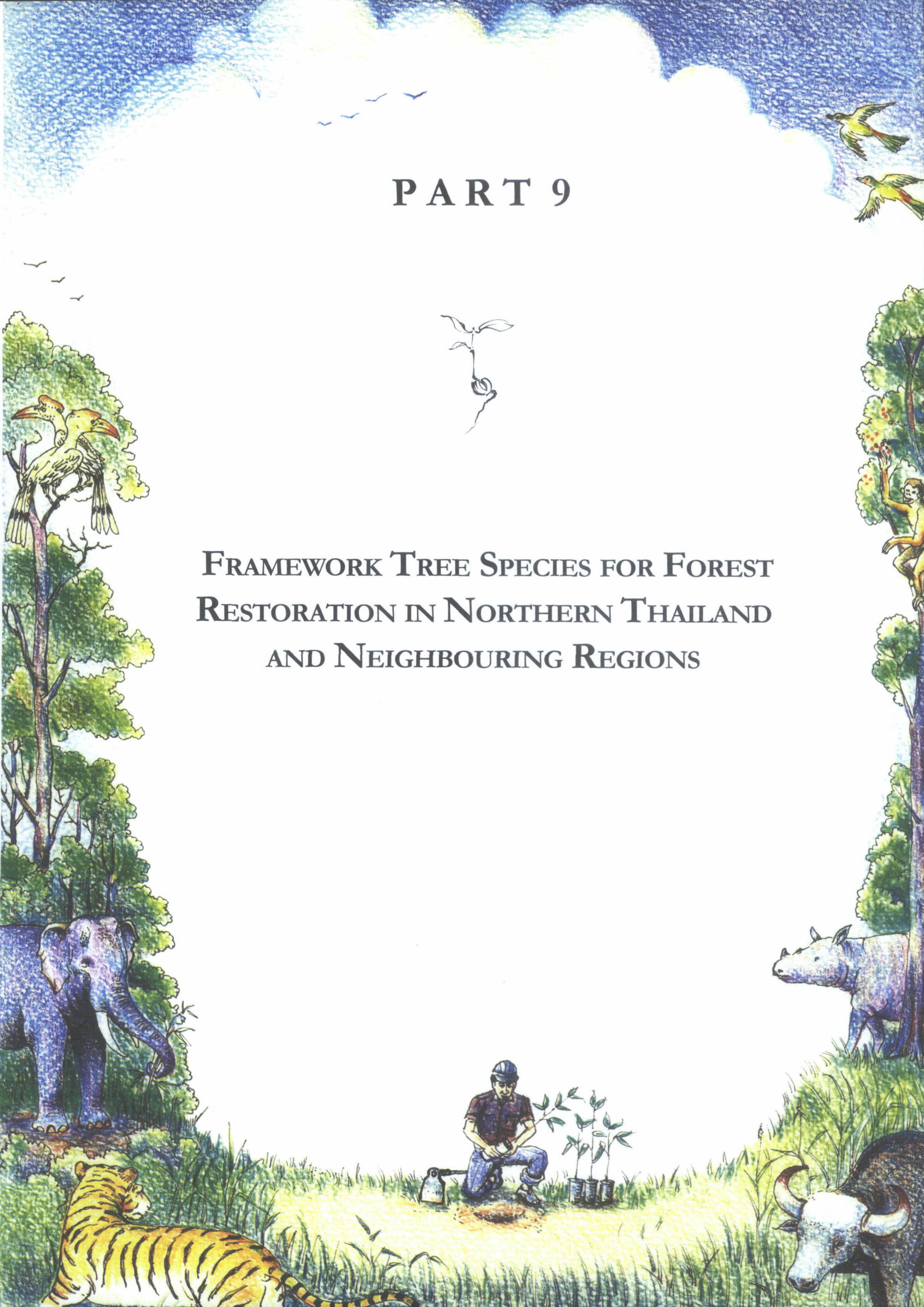
Planting, maintenance and monitoring costs can be divided into i) materials, ii) labour and iii) transportation. Materials for planting include glyphosate herbicide, fertilizer and a bamboo pole and cardboard mulch mat for each tree planted. Add to the budget the cost of 1-1.5 litre of glyphosate concentrate per rai. Half a 50-kg-bag of fertilizer is required for each rai with 4 applications in the first year and 3 in the second. Therefore, add the cost of 3½ bags of fertilizer per rai. Corrugated cardboard for mulch mats can be bought by the kilogram at recycling centres, but ask local shop-owners to donate their cardboard waste to the project. Bamboo stakes may be bought or cut from degraded areas by local labour. At current rates[1], the cost of these materials amount to 2,000-2,500 baht per rai (assuming 500 trees per rai).

Labour is the most costly budget item, with fire prevention being the largest labour cost. Therefore, the financial viability of forest restoration often depends on the extent to which paid labour can be replaced with volunteers. It is usually easy to find people from local schools and businesses to help out on planting day. Fire prevention is usully designated a voluntary "community activity" by village committees. Therefore, weeding and fertilizer application are the two activities that are most likely to require paid labour.

To calculate labour costs, begin with the figures in Table 8.2. Look at the suggested labour per rai required for site preparation, planting, weeding and fertilizer application, monitoring and fire-break cutting. Remove any activities, for which voluntary help can be obtained. Then recalculate the total number of days labour required per rai over two years. Multiply that number by the number of rai to be planted and then by the local daily labour rate to get the total cost of area-dependent labour. Next, consider the size of the fire prevention team needed. In northern Thailand, fire prevention is usually necessary for 90 days from mid-January until the end of April, 24 hours per day. Multiply the number of people on the fire prevention team by the number of days required and the daily labour rate to get the total fire prevention costs per year. Transportation costs depend on the distance from the nursery to the planting site and must be calculated individually.

Provided that at least fire prevention is done voluntarily, current total costs in Thailand, amount to approximately 10,000 baht per rai (=US$ 1623/ha), including tree production and all materials and labour for planting, maintenance and monitoring over 2 years. If all field labour is voluntary, the price of trees and materials totals 3,500 baht per rai (=US$ 571/ha)[1].

[1]Cost calculations made in 2005

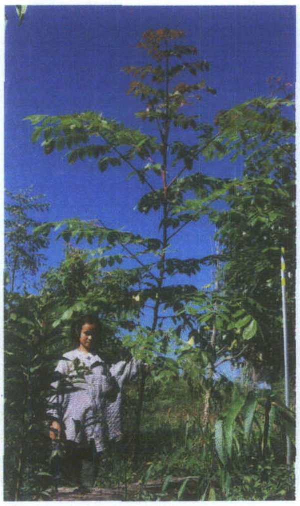


PART 9

Framework Tree Species for Forest Restoration in Northern Thailand and Neighbouring Regions

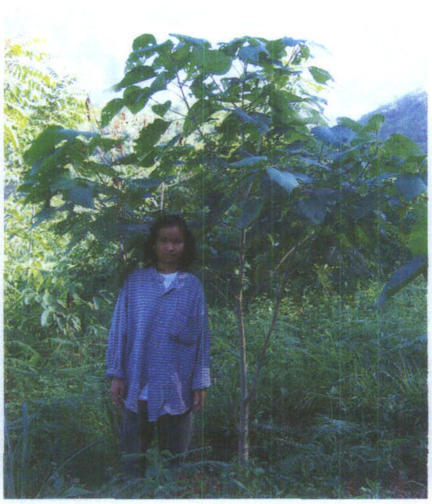
What Makes an Effective Framework Tree Species?

***High survival and growth rates** after planting out in the harsh conditions of deforested sites and development of **dense, spreading crowns** to shade out herbaceous weeds. Trees below photographed 17 months after planting.*



Acrocarpus fraxinifolius, *4 metres tall after 17 months.*

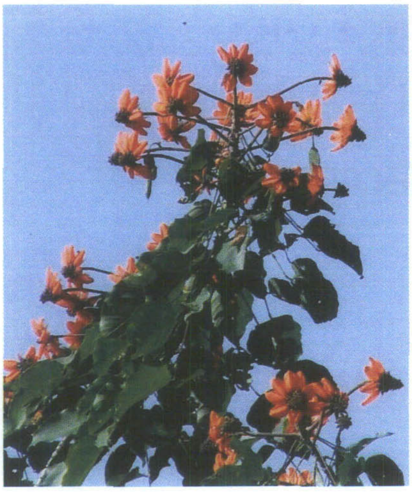
Melia toosendan *survival >90%; 5-7 m tall.*



Gmelina arborea. *Large leaves make dense, shady crowns > 3 m broad.*

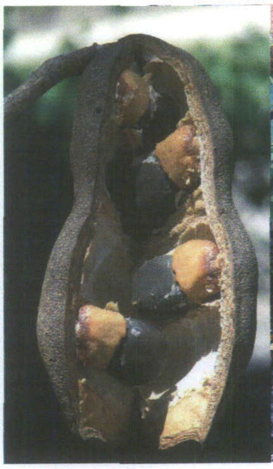
Spondias axillaris. *Low stem forks result in multiple crowns.*

*Provision of nectar-rich flowers, nutritious fruits or nesting sites to **attract seed-dispersing animals** at a young age.*



The nectar-rich flowers of Acrocarpus fraxinifolius *(above) act as a magnet to seed-dispersing animals.* Erythrina subumbrans *(left) flowers within 4 years after planting.*

Prunus cerasoides *flowers, fruits (above left) and provides bird nesting sites (above right) by 3 years after planting.*



Easy to grow in nurseries

Simple techniques can accelerate tree production. For example nicking the tough coat of Afzelia xylocarpa *seeds (above) reduces dormancy from >1 year to 19 days, enabling saplings to be grown to a plantable size within 14 months.*

Figs (left) - keystone food for seed-dispersers in planted plots.

Resilience after fire

Spondias axillaris *saplings have high survival rates after burning. This one (right) survived a fire just 8 months after planting out. The following rainy season, it grew taller than 2 m.*

Framework Tree Species for Forest Restoration in Northern Thailand and Neighbouring Regions

In this Part, we present details of 41 forest tree species, native to N. Thailand, which act effectively as framework tree species, based on the results of FORRU's research program since 1994 (according to the criteria presented in Part 5, Section 1). Before selecting any of the species suggested here for planting, first check to make sure that they are indigenous to the area being planted and that the elevation of the planting site falls within the elevation range of the species selected. FORRU-CMU has tested only about 400 tree species out of the >1,100 recorded for N. Thailand. So, our work is far from complete. We are constantly collecting new data and updating our list of recommended framework species. So, just because a species is not listed here, does not necessarily mean that it should not be planted. For assistance with species selection, based on the latest information, please contact FORRU-CMU directly (see page 200). An explanation of the format of each species entry is provided below.

Where does it grow?

This information comes from various regional floras and from the CMU Herbarium Database (based on the collections of J. F. Maxwell). For abbreviations of forest types, see Part 2. DBH = diameter at breast height.

What are its distinguishing characteristics?

Space limitations allow only the most characteristic features of each tree species to be described, based on examination of voucher specimens in the CMU Herbarium. For complete species descriptions, please refer to your country flora or other botanical texts. For an explanation of botanical terminology, please refer to the glossary at the end of the book.

Why is it a framework species?

Field performance data cited are those from FORRU's experimental plots, mostly from the end of the second rainy season after planting (see Part 5, Section 3). Information on the attractiveness of each species to seed-dispersing wildlife comes from direct observations in plots up to 7 years after planting. RCD=root collar diameter.

How are saplings grown?

For general advice on growing trees, see Part 6. Here, we present specific techniques for each species, from FORRU's nursery research. For all species, collect seeds from >10 trees, close to the planting site, to maintain genetic diversity. GP=germination percentage; MLD= median length of dormancy (Part 3, Section 5); TNT=total nursery time from seed sowing to planting out.

How should saplings be planted and cared for?

Follow the planting and after-care methods presented in Part 7. Here, we present a few particular requirements of each species or notable responses to silvicultural treatments, based on data from FORRU's experimental plots.

What can this species be used for?

As well as promoting biodiversity recovery, framework trees have economic uses. So, a selection of published uses is presented for each species. This information is useful where framework species are used for community forestry. **Do not apply any of the medicinal uses stated, without medical supervision.**

Acrocarpus fraxinifolius Wight *ex* Arn. (LEGUMINOSAE, CAESALPINIOIDEAE)

Sadao Chang

A very large, light-demanding, deciduous, tree, growing up to 60 m tall (DBH to 2.4 m). The crowns of older trees often emerge above the forest canopy.

Where does it grow?

In E. India, S. China, Myanmar, Thailand, Laos, Vietnam, Borneo, Sumatra and Java. In N. Thailand, it is rare in EGF at elevations of 1000 to 1200 m.

What are its distinguishing characteristics?

Larger trees with buttresses. ***Bark:*** grey, with brown lenticels. ***Leaves:*** doubly pinnate; leaf segments 4-14 x 2-7 cm, ovate; young ones pink and hairy. ***Flowers:*** bisexual, in dense paniculate clusters on leafless branches, petals red; January to March, ***Fruits:*** pods, black, elongated and flattened, 8-16 x 1-2 cm; seeds, 10-18 per pod, ovate, light brown 4.6-6.8 x 3.4-4.2 mm; February to May; wind-dispersed.

Why is it a framework species?

Planted *A. fraxinifolius* saplings grow rapidly (>2 m by end of 2nd rainy season) and develop crowns boader than 2 m across, which effectively shade out weeds, but survival is marginal. This species coppices readily and regenerates well after fire (70% survival of trees with RCD >20 mm, burnt 21 months after planting). Its nectar-rich flowers attract birds and squirrels and it is favoured by birds as a perching site.

How are saplings grown?

Collect black pods, March to April. Air-dry them until they split, releasing the seeds. Chip away part of the seed coat with nail clippers or put seeds in sulphuric acid for 5-10 minutes. Sow seeds in trays in full sunlight; GP c.50%; MLD can be reduced to 4 days with above treatments. Seedlings are prone to damping-off and attack by caterpillars, so take appropriate precautions. Pot seedlings after first true-leaf pairs expand and stand containers in sunlight. Saplings usually grow tall enough (>30 cm) for planting out by 2nd planting season after seed collection (TNT 15-16 months). Alternatively, store seeds at ambient temperature, then treat and sow them in November.

How should saplings be planted and cared for?

Survival can be substantially increased by laying cardboard mulch at planting time and by continuing weeding and fertilizer application into the dry season.

What can this species be used for?

Its durable timber is prized for house construction and furniture and is used as firewood and to make charcoal. The foliage makes good cattle fodder. Planted for shade in coffee plantations; to stabilize river banks and terraces and to increase soil nitrogen content.

Afzelia xylocarpa (Kurz) Craib (Leguminosae, Caesalpinioideae) — Makah Mong

A large, deciduous tree, growing up to 30 m tall (DBH to 1.5 m); listed as an endangered species, due to over-exploitation for its valuable timber.

Where does it grow?

Throughout Indochina, except S. Thailand. In N. Thailand it is common in BB-DF, at elevations of 350 to 500 m.

What are its distinguishing characteristics?

Trunks of larger trees have small buttresses. ***Bark:*** light brown, deeply cracked ***Leaves:*** once pinnate, with 3-5 pairs of leaflets; leaflet blades 5-9 x 4-5 cm; often leafless January-February. ***Flowers:*** in panicles, red, 5-15 cm long; from March to April. ***Fruits:*** pod, woody, dehiscent, elliptical-oblong, black when mature, 12-20 cm long; seeds, black or dark brown, 2 x 1.5 cm, with large, yellow, basal aril; fruiting June to March; animal-dispersed.

Why is it a framework species?

A. xylocarpa saplings, planted in degraded deciduous forest sites, survive well (>80% by end of 2nd rainy season), but grow rather slowly. They develop broad, dense crowns, which suppress weed growth and provide bird perches. Due to its nitrogen-fixing capability, this species is suitable for restoring lowland sites, where soil fertility is low.

How are saplings grown?

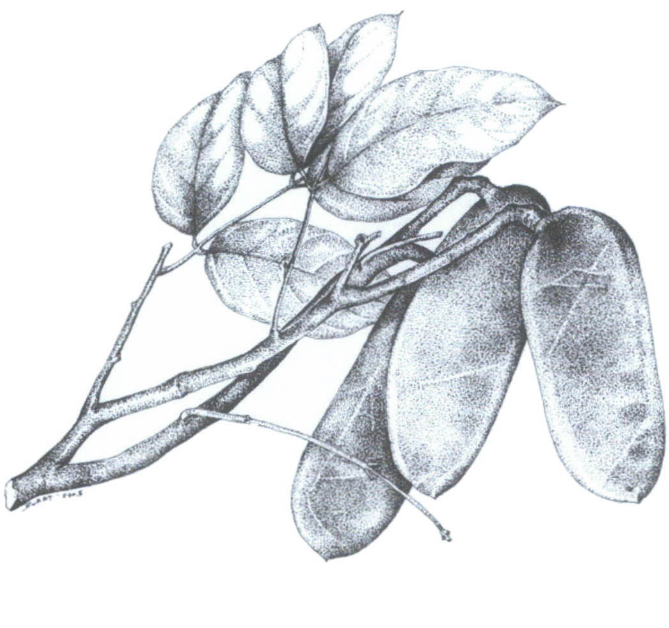
Collect pods from the ground in May. Sun-dry them until they open and remove the seeds. With a knife, remove the aril (taking care not to damage the embryo) and chip away part of the seed coat, at the opposite end to where the aril was attached. Soak seed in water overnight, then sow them directly into containers (1 per container). Germination starts about 3 weeks after sowing and is synchronous. GP typically 60-70%; MLD 19 days. This species is prone to leaf-eating insects, so take appropriate precautions. Saplings are ready for planting out by the 2nd planting season after seed collection (TNT 14 months), when they are about 40-50 cm tall. Seeds may be stored for up to 1 year at ambient temperatures.

How should saplings be planted and cared for?

Apply a cardboard mulch mat at planting time. Weed and apply fertilizer as necessary. This species is very suitable for direct seeding.

What can the species be used for?

Its hard, attractive wood is highly valued for high quality furniture, carvings, house construction and flooring. Juice from the bark called "catechol" is used for tanning leather. *A. xyloxarpa* fixes nitrogen and is, therefore, suitable for soil improvement and agro-forestry. Various parts of the plant have medicinal properties.



Archidendron clypearia (Jack) Niels. (Leguminosae, Mimosoideae) — Mah Kham Pae

A small, understorey, shade-tolerant, evergreen tree or treelet, growing up to 15 m tall.

Where does it grow?

From Sri Lanka, India, Myanmar through S. China, Indochina, Malaysia, Indonesia and the Philippines. In N. Thailand, it is common in secondary EGF, at elevations of 1000 to 1650 m. Naturally colonizes fallow fields from 3 years after cultivation has ceased.

What are its distinguishing characteristics?

Bark: distinctive red-brown, with zig-zag internodal lines. ***Leaves:*** doubly compound, 15-50 cm long; leaflets opposite, upper ones largest, 4-7 x 2-3 cm; mature blades dark green above, hairy below; petiole ridged/flanged. ***Flowers:*** in large branched clusters; white or pale yellow; February to March. ***Fruits:*** pods, orange-brown when ripe, thin-walled, spirally dehiscing to expose glossy black oval-shaped seeds (6-8 per pod); fruiting March to June; wind-dispersed.

Why is it a framework species?

A. clypearia saplings survive well after planting out in ex-EGF sites (>70% survival by end of 2nd rainy season). They grow slowly at first, but growth accelerates 2-3 years after planting. They flower and fruit in the 4th year after planting and produce second-generation seedlings, which grow well in the shade of framework plots, from 6 years after planting. Recruitment of other tree species, beneath the crowns of *A. clypearia* trees, has been observed from the 3rd year after planting. The species' nitrogen-fixing capability makes it suitable for improving soils in degraded areas.

How are saplings grown?

Collect ripe pods from parent trees from May to June. Remove seeds from pods, soak them in water overnight, and sow them in germination trays in full sunlight. GP typically 50-70%; MLD 14 days. Prick out seedlings after expansion of the first true-leaf pairs. Saplings are ready for planting by the 2nd planting season after germination, when they are about 30 cm tall (TNT 13-14 months).

How should saplings be planted and cared for?

This species responds well to cardboard mulch placed around the trees at planting time.

What can the species be used for?

Timber for joinery, furniture, fencing, household utensils, crates, boxes and firewood.

Balakata baccata (Roxb.) Ess. (EUPHORBIACEAE) — Salee Nok

Synonym: *Sapium baccatum* Roxb.

A common, large, pioneer, evergreen tree, growing up to 25 m tall (DBH to 60 cm).

Where does it grow?

From the eastern Himalayas and N. India to S. China, Myanmar, Thailand and further south-east to peninsular Malaysia, Sumatra and Borneo. In N. Thailand, it is common in MXF and EGF, at elevations of 400 to 1350 m, often along streams at lower elevations.

What are its distinguishing characteristics?

Bark: thick, roughly, vertically cracked, blackish; large lenticels when young. ***Leaves:*** spirally arranged, simple; blades ovate to elliptic, often whitish below, 8-18 x 3-8 cm. ***Flowers:*** minute, unisexual, in branched spike-like clusters; February to August. ***Fruits:*** drupes, fleshy, globose, dark purple-black when ripe, 14.9 x 14.3 x 12.1 mm; pulp white and fibrous; 1-2 black seeds (5.3 x 4.2 x 4.1 mm) per fruit; April to December; dispersed by squirrels and birds.

Why is it a framework species?

Although survival of planted *B. baccata* saplings is sometimes marginal, those that survive usually grow very rapidly, averaging >3 m tall, with 2.5-m-broad crowns, by the end of the 2nd rainy season. Branching occurs 0.5 -1.0 m above ground, resulting in dense crowns, which shade out weeds very effectively and provide a secluded habitat for nesting birds as early as the 2nd year after planting. Fruits are attractive to birds and mammals. Seedlings of other tree species establish beneath *B. baccata* crowns by the 4th year after planting. More research is needed to increase the post-planting survival rate of this species.

How are saplings grown?

Collect ripe (purple) fruits in July. Soak them in water for 48 hrs and clean off the flesh. Sun-dry the pyrenes, then sow them in trays in full sunlight. Germination is asynchronous and continues for 16 weeks. GP up to 70%; MLD typically 60-70 days. Young seedlings are prone to stem breakage, attack by caterpillars and bacterial blight, so take appropriate precautions. Prick out seedlings after expansion of first true leaf pairs. Saplings are usually ready for planting by the 1st planting season after germination (TNT 12 months). Pruning kills this species.

How should saplings be planted and cared for?

Saplings of this species are often weak-stemmed, so extra care during transportation and staking can reduce post-planting mortality. Never plant *B. baccata* where may become shaded. Suitable for direct seeding.

What can the species be used for?

This species has soft non-durable wood, suitable for temporary construction, boxes and crates. Its fruits are edible and its bark is an ingredient in several traditional medicines.

Bischofia javanica Bl. (EUPHORBIACEAE) — Dteum

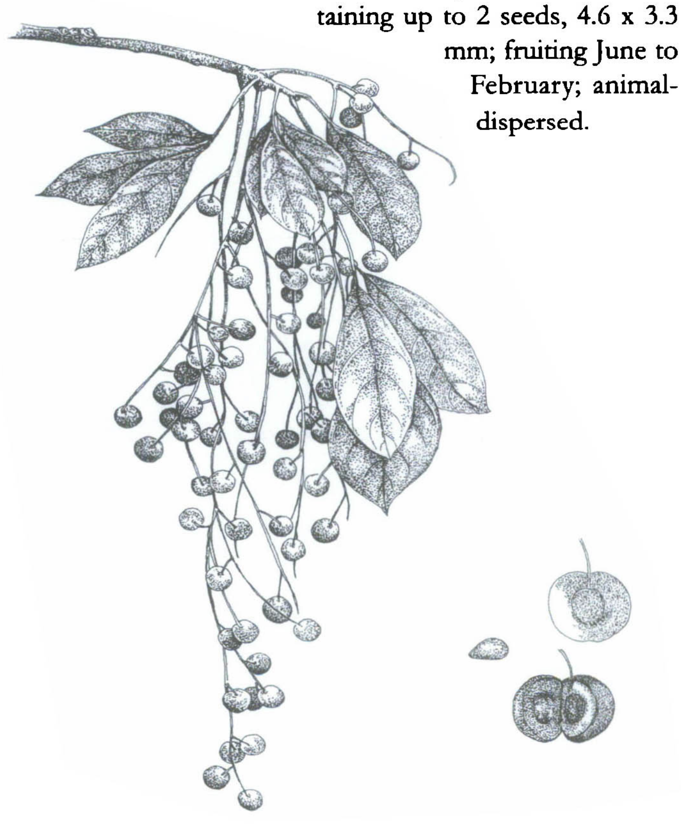
A large, common, light-demanding, evergreen (or leaf-exchanging) tree, growing up to 35 m tall (DBH to 80 cm).

Where does it grow?

From the Himalayas to China, Indochina, East Asia, Malaysia, N. Australia and the Pacific islands of Tonga and Samoa. In N. Thailand, it grows in EGF, MXF and BB-DF, often along streams at elevations of 525 to 1250 m.

What are its distinguishing characteristics?

Bark: thin, vertically fissured, scaly or flakey, reddish brown; sap dark red. ***Leaves:*** spirally arranged, trifoliate; blades, ovate or elliptic, hairless, 6.5-14.5 x 3.5-6.5 cm; margin shallowly serrate; leaf-exchanging February to March at low elevations. ***Flowers:*** numerous in axillary panicles, greenish-yellow, without petals, c.2 mm long; February to March. ***Fruits:*** slightly fleshy drupes, globose, brown-black when ripe, 5-10 x 5-10 mm; 3 or 4 locules per fruit, each containing up to 2 seeds, 4.6 x 3.3 mm; fruiting June to February; animal-dispersed.



Why is it a framework species?

Survival of planted saplings is usually high (60-80% by end of the 2nd rainy season), but growth can be slow. Birds nest in this species by the 5th year after planting and it fruits within 6 years. Natural recruitment of tree species occurs beneath 6-year-old trees. It coppices and survives well after fire (>80% survival of trees burnt 33 months after planting; RCD>20 mm).

How are saplings grown?

Collect ripe fruits in October (the earlier the better). Crush them and extract seeds in a sieve under running water. Sun-dry seeds and sow them shallowly and well-spaced in 1:1 forest soil and sand, to prevent damping-off. Germination is asynchronous, continuing for 6 weeks: GP up to 80%; MLD 26 days. Prick out seedlings after expansion of first true-leaf pairs. Fertiliser application is important for this species. Seedlings are prone to caterpillars, stem gall larvae and sap-sucking mites, which cause leaf curling. Destroy diseased plants and spray survivors. If fertilizer is applied, saplings are ready for planting by the 1st planting season (TNT 9 months).

How should saplings be planted and cared for?

B. javanica responds well to cardboard mulch and fertilizer. Make sure planted saplings do not become shaded by neighbouring trees.

What can the species be used for?

Timber used for construction, beams, flooring, furniture, joinery, carving and charcoal. Also used for paper-making. Bark produces a red dye and contains tannin.

Castanopsis acuminatissima (Bl.) A. DC. (FAGACEAE) — Gaw Duey

A medium-sized, shade-tolerant, evergreen tree, growing up to 25 m tall (DBH to 1 m).

Where does it grow?

From NE India to China, Taiwan, Thailand, peninsular Malaysia, Java, Sabah, Sulawesi and Papua New Guinea. In N. Thailand, it is abundant in EGF, EGF-PINE and MXF at elevations of 760 to 2100 m.

What are its distinguishing characteristics?

Bark: grey-brown, thick, vertically cracked. ***Leaves:*** simple, spirally arranged; blades, lanceolate, 10-15 x 3-5 cm; margin serrate towards apex; mature blades, dark green above, light green with sparse, short, white hairs beneath. ***Flowers:*** in dense erect panicles, cream-coloured, fragrant, c.5 mm long; December to February. ***Fruits:*** solitary nuts, 8-10 x 7-8 mm, completely enclosed within a cupule (c.1 cm long), covered in short spines (in widely spaced clusters), light brown when ripe; September to October; animal-dispersed.

Why is it a framework species?

C. acuminatissima saplings survive well and grow rapidly after planting out (with mulching, >70% surival; >2.5 m tall; canopy >1.3 m broad by end of 2nd rainy season). They are used by nesting birds from 2.5 years after planting. This species coppices easily, enabling rapid regeneration after fire.

How are saplings grown?

Collect brown fruits in October. Remove the cupules. Drop nuts into water and discard the non-viable ones which float. Sow nuts in germination trays in partial shade. GP typically 50%; MLD 13 days, but germination is asynchronous and may continue for 60 days. Prick out seedlings after expansion of first true-leaf pairs. Saplings are ready for planting out by the 2nd planting season after germination (TNT 21 months).

How should saplings be planted and cared for?

This species responds very well to cardboard mulch placed around the trees at planting time.

What can the species be used for?

Nuts are edible and leaves can be used as cattle fodder. The timber is suitable for construction and is good firewood. In N. Thailand, cut branches are used to culture mushrooms. The bark contains tannins, used as a laxative and it is sometimes chewed with betel nut.

Castanopsis tribuloides (Sm.) A. DC. (Fagaceae) — Gaw Bai Liam

A shade-tolerant, medium-sized, evergreen tree, growing up to 18 m tall (DBH to 70 cm).

Where does it grow?

From the Himalayas to China, Myanmar and Indochina. In N. Thailand, it is abundant in MXF and EGF-PINE, often as a late successional species at elevations of 650 to 1650 m.

What are its distinguishing characteristics?

Bark: dark grey-black or brown, thick, vertically cracked. ***Leaves:*** spirally arranged, simple; blades oblong to lanceolate, margin shallowly serrate towards apex, glossy dark green above, light silvery green or yellow below, 10-16 x 2.5-5.5 cm. ***Flowers:*** unisexual, in erect axillary panicles; males numerous, fragrant; females inconspicuous; April to May. ***Fruits:*** nut, sub-globose, brown when ripe, 7.2 x 6.4 x 5.9 mm, completely enclosed in a spiny cupule with rigid spines 3-5 mm long; one seed per nut; fruiting most commonly September to November, but not every year; dispersed by civets and other animals.

Why is it a framework species?

Saplings of *C. tribuloides* achieve excellent survival rates and acceptable growth rates after planting out (>70% survival; >1.5 m tall, by end of 2nd rainy season). Although, initially, crowns are rather narrow, they effectively shade out weeds. The species flowers from the 3rd year after planting and fruits from the 5th. It is highly resilient after fire, readily coppicing. It also regenerates well from seed. It is very shade-tolerant and ideal for enrichment planting beneath an established forest canopy.

How are saplings grown?

Collect brown nuts in September. Remove cupules, drop nuts into water and remove the non-viable ones, which float. Sow nuts in germination trays in partial shade. GP usually >80%; MLD 31 days; germination asynchronous, continuing for up to 80 days. Prick out seedlings after expansion of first true-leaf pairs. Containerized saplings grow slowly and must be kept in nurseries until the second planting season after germination (TNT 22 months). To produce planting stock more quickly, try cultivating wildlings in the nursery (see Box 6.2).

How should saplings be planted and cared for?

Plant in shady places. This species responds particularly well to cardboard mulch.

What can the species be used for?

Timber can be used for light construction and firewood. Nuts are edible. Leaves are suitable for animal fodder. Decaying wood is used for mushroom cultivation.

Elaeocarpus lanceifolius Roxb. (ELAEOCARPACEAE)

Ma Meun, Pee Pai

A medium-sized, shade-tolerant, evergreen tree, growing up to 20 m tall (DBH to 40 cm).

Where does it grow?

From Yunnan and India, across Indochina to Indonesia. In N. Thailand, it is common in EGF at elevations of 900 to 1550 m.

What are its distinguishing characteristics?

Bark: grey, thin, slightly rough. ***Leaves:*** spirally arranged, simple; blades narrowly elliptic or lanceolate, 8-17 x 4-7 cm, tapering at both ends. ***Flowers:*** bisexual, in axillary racemes, 5-12 cm long; sepals 5, lanceolate, 4-5 mm; petals 5, cream or white, obovate, slightly longer than sepals, margin ciliate; June to July. ***Fruits:*** drupes, ovoid, brown or cream when ripe, 3.5 x 2-3 cm; October to November; animal-dispersed.

Why is it a framework species?

Saplings of *E. lanceifolius* achieve excellent survival rates and acceptable growth rates after planting out (>80% survival; >1.8 m tall by end of 2nd rainy season). They grow dense crowns (>1 m across), which accelerate early site recapture. Many of bird and mammal species are attracted to the fleshy fruits of this species.

How are saplings grown?

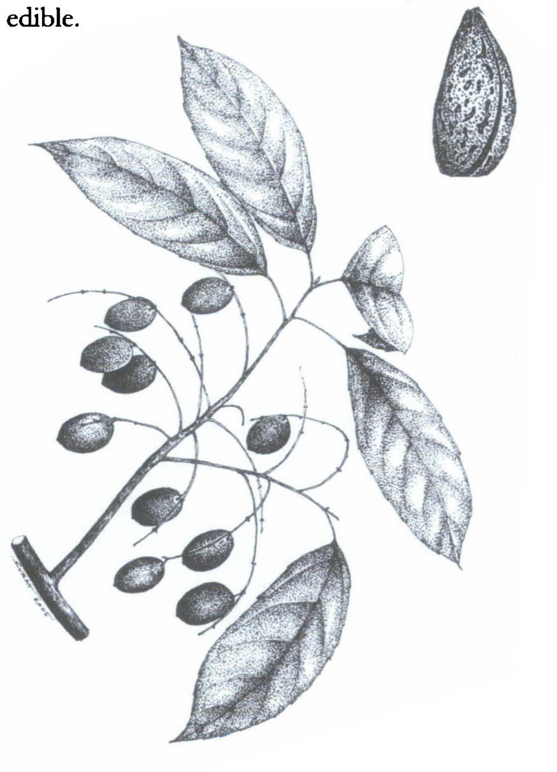
Collect ripe fruits from the ground in October or November. Soak them in water overnight; then rub off the flesh. Scarify the pyrenes with a knife; then soak them overnight again. Remove any non-viable ones which float. Sow the pyrenes in germination trays in shade. GP usually low, 25-50%; MLD typically 250-260 days. Germination can be increased by collecting aged pyrenes from the ground under parent trees or storing them (in a bucket with no lid at ambient temperatures) for several months prior to sowing. Prick out seedlings after expansion of first true-leaf pairs. Seedlings should be ready for planting in the field by the 2nd planting season after germination (TNT 20-21 months). Planting stock may be produced more rapidly from leafy cuttings.

How should saplings be planted and cared for?

Cardboard mulch mats, placed around saplings at planting time, significantly reduce post-planting mortality of this species. Seeds are highly susceptible to predation by rodents, so it is not suitable for direct seeding.

What can the species be used for?

The wood is soft and used for light construction, tea boxes and charcoal making. Fruits are edible.



Erythrina subumbrans (Hassk.) Merr. Tawng Lahng Bah (Leguminosae, Papilionoideae)

A medium-sized, pioneer, deciduous tree, growing up to 25 m tall (DBH to 86 cm).

Where does it grow?

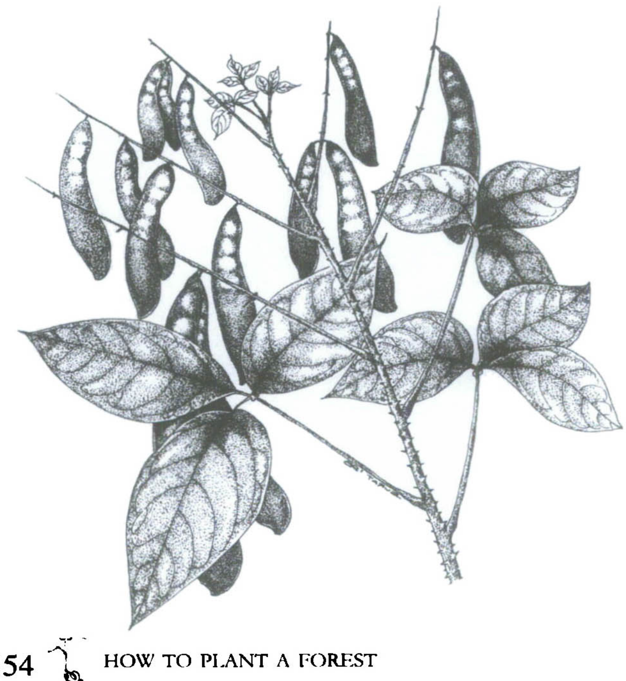
From India, Myanmar and Indochina to Malaysia, Fiji and Samoa. In N. Thailand, it grows sparsely in EGF and MXF at elevations of 500 to 1680 m.

What are its distinguishing characteristics?

Bark: soft, grey, with spine-tipped black tubercles. ***Leaves:*** spirally arranged, trifoliate; leaflet blades ovate, margin entire, terminal leaflet 10-14 x 8-12 mm. ***Flowers:*** bisexual, 4-5 cm long; petals bright red; December to March, often when leafless. ***Fruits:*** pods, brown, 15.5 x 1 cm; seeds smooth, dark brown, kidney-shaped, 1 x 0.9 cm; March to April; pods wind-dispersed.

Why is it a framework species?

E. subumbrans saplings achieve excellent survival and growth rates after planting out (>80% survival; >2.5 m tall, crowns 2.6-2.8 m across, by end of 2nd rainy season). Their broad, deciduous, crowns produce dense leaf litter, creating excellent conditions for germination of tree seeds on the forest floor. They flower, fruit and attract nesting birds from the 4th year after planting. The vivid scarlet flowers produce nectar, which attracts many bird and squirrel species. The seed rain from these animals results in natural recruitment of many tree species around *E. subumbrans* trees within 5 years. As a legume, this species adds nitrogen to nutrient-poor soils.



How are saplings grown?

Collect seeds from fallen pods in March. Soak them in water overnight. Sow those that start to swell and discard any non-viable ones, which float. Sow seeds directly into containers, in full sunlight, and use wire mesh to protect them from rats and squirrels. GP typically 40-60%; MLD 7-14 days. Take precautions against leaf-folding caterpillars (Lepidoptera, Pyralidae), which defoliate seedlings in the late rainy season. Do not apply fertilizer or prune this species. Saplings can be planted out when 30 cm tall, usually 3-4 months after germination.

How should saplings be planted and cared for?

E. subumbrans saplings have weak stems, so care is needed when handling them. Staking can reduce post-planting mortality. They respond well to fertilizer application and mulching after planting. However, planted trees are susceptible to a stem-boring insect pest, which can kill even mature trees. Do not plant *E. subumbrans* tree where they might become shaded.

What can the species be used for?

Cut branches of *E. subumbrans* root well, when planted in soil, so they are used to construct "living fences". Its lightweight timber is used for carving and for making various utensils. Its foliage is used for cattle fodder.

Eugenia fruticosa (DC.) Roxb. (MYRTACEAE) — Wa Kee Gwang

A small to medium-sized, pioneer, evergreen tree, growing up to 12 m tall.

Where does it grow?

In India, Myanmar, China and Thailand. In N. Thailand, it is common in EGF-PINE, DOF and BB-DF, at elevations of 350 to 1525 m. It frequently establishes in deforested sites and is one of the most common recruit species establishing in framework plantings aged 4 years or older.

What are its distinguishing characteristics?

Bark: dark brown, flaking. ***Leaves:*** simple, opposite; blades 7.5-11.5 x 3.5-6.5 cm; petiole slightly winged. ***Flowers:*** corolla greenish yellow; calyx cup 2-3 mm, outer stamens and style 2-4.5 mm; March to April. ***Fruits:*** berry, globose or ovoid, blackish purple when ripe, 8 x 13 mm, pericarp juicy; seed, one per fruit, green or light brown, 8 x 6-7 mm; May to July; animal-dispersed.

Why is it a framework species?

Planted *E. fruticosa* saplings achieve acceptable survival and growth rates (60-70% survival; >1.6 m tall; crowns >1 m broad, by end of 2nd rainy season). Their dense crowns effectively shade out weeds. Deer and bulbuls eat the fruits and nectar-rich flowers attract many birds and squirrels. However, this species takes longer than 7 years to commence flowering.

How are saplings grown?

Collect ripe fruits from the ground in May. Remove the fruit flesh; drop seeds into water and discard the non-viable ones which float. Sow seeds in trays in full sunlight, then move trays into shade immediately after germination. GP typically >90%; MLD 27-35 days. Young seedlings are prone to attack by aphids and caterpillars, so take precautions. Prick out seedlings after expansion of first true-leaf pairs. Seedlings grow to a plantable size by the 2nd planting season after germination (TNT 14 months).

How should saplings be planted and cared for?

Planted *E. fruticosa* trees respond well to cardboard mulch. They grow slowly at first, but growth accelerates 4-5 years after planting. Suitable for direct seeding.

What can the species be used for?

Fruits are edible, by both humans and wild animals, and they are traditionally used to make an alcoholic beverage.

***Eugenia albiflora* Duth. *ex* Kurz** is a closely related species, requiring a similar propagation protocol and having similar framework characteristics. It fruits within 4 years after planting out.

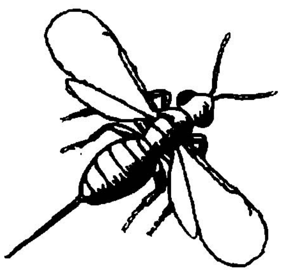
Ficus species (MORACEAE)

Fig Tree Species Sai, Madeua

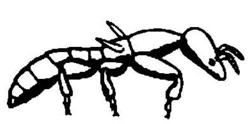
Ficus species can grow as vines, woody climbers, shrubs, treelets or large forest trees. Most function well as framework species, except for the climbers, which should not be planted, at least during the initial phases of forest restoration. Since most *Ficus* tree species share similar properties, they are grouped together here.

Where do *Ficus* species grow?

The genus (>1,000 species) is distributed mostly throughout tropical and subtropical America, Africa, Asia and Australasia. At least 35 different fig tree species are distributed amongst all the forest types of N. Thailand, although more species (22) grow in evergreen forests than in deciduous forest types (13). Some species can grow to an enormous size, particularly "stranglers" such as *F. altissima*, whereas a few smaller species grow on rocks along streams (*e.g. F. heteroplura*). Some smaller *Ficus* species (*e.g. F. hispida, F. hirta* and occasionally *F. semicordata*) naturally colonize deforested areas. If present in sufficient numbers, they need not be planted, but where absent, they are recommended for planting.



Female fig wasps pollinate fig flowers. They lay eggs in the gall flowers, then die.



Wingless male wasps hatch first. They mate with the females, while the females are hatching, then die.

What are the distinguishing characteristics of *Ficus* spp trees?

Figs are the most characteristic feature of mature *Ficus* spp trees. They are usually highly visible, often on trunks or branches, for long periods every year. Often referred to as "fruits", figs are actually the swollen stalks of inflorescences (receptacles), which have become inverted to enclose many tiny flowers or fruits within. The whole structure is termed a "syconium". Flowers within the figs are pollinated by fig wasps; usually a different wasp species for each *Ficus* species. Female wasps enter figs via a small hole at the apex and lay their eggs in infertile, "gall" flowers, simultaneously pollinating fertile, female fig flowers. Male wasps hatch first and mate with the females as they emerge. Mated female wasps pick up pollen from male flowers inside the figs, before flying to another *Ficus* tree, of the same species, to lay

SPECIES	HABIT	LEAFING	HABITAT*	ELEVATION (m)
F. altissima Bl.	T (st)	E	BB-DF MXF	350-1050
F. benjamina L. var. *benjamina*	TL (st)	E	MXF EGF	350-1400
F. callosa Willd.	T	D	EGF	790-1400
F. fistulosa Reinw. ex Bl.	TL	ED	Disturbed areas in BB-DF MXF EGF	350-1400
F. glaberrima Bl.	T	E	Near streams in BB-DF MXF EGF	450-1200
F. hirta Vahl var. *hirta*	L	E	Disturbed areas in BB-DF MXF EGF	350-1150
F. hispida L. f. var. *hispida*	TL	E	Disturbed areas in BB-DF EGF	350-1525
F. microcarpa L. f.	T (st)	E	Streams in BB-DF MXF EGF	350-1050
Ficus racemosa L.	T	D	MXF especially along streams	350-500
F. semicordata B.-H. ex J.E. Sm.	TL	D	Disturbed areas in BB-DF EGF EGF-PINE	350-1550
F. subincisa J.E. Sm.	LS	E	Disturbed areas in MXF EGF	825-1400
F. superba (Mig.) Mig.	T	D	MXF EGF	750-1350

T=tree; L=treelet; (st)="strangler"; E=evergreen; D=deciduous; *habitat abbr. see Part 2 their eggs. Figs are therefore vital nurseries for their pollinators, so each *Ficus* and wasp species rely on each other for reproduction. The life cycle of the wasp is short so, somewhere in the forest, figs of each species must be available nearly all year round. Otherwise the wasps would die out, leaving *Ficus* trees unable to reproduce.

Another characteristic of all *Ficus* trees is exudation of white, sticky latex from any cut surface; a feature also shared with other genera in the family, Moraceae.

The large roots of some *Ficus* trees are often exposed above ground. Finer, but very tough and fibrous, adventitious roots are produced in a very dense network.

The bark of *Ficus* trees is usually smooth, often pale grey or brown. Leaf arrangement and shapes are very variable.

Why do *Ficus* trees function so well as framework species?

Two main characteristics make most *Ficus* tree species excellent framework tree species. Firstly, their very dense root systems enable them to survive and grow well under the harshest of conditions and to grow back rapidly after burning or slashing. Such root systems allow most species to retain their leaves throughout the dry season, by tapping into soil moisture deep underground. This makes *Ficus* trees excellent for preventing soil erosion and stabilizing river banks.

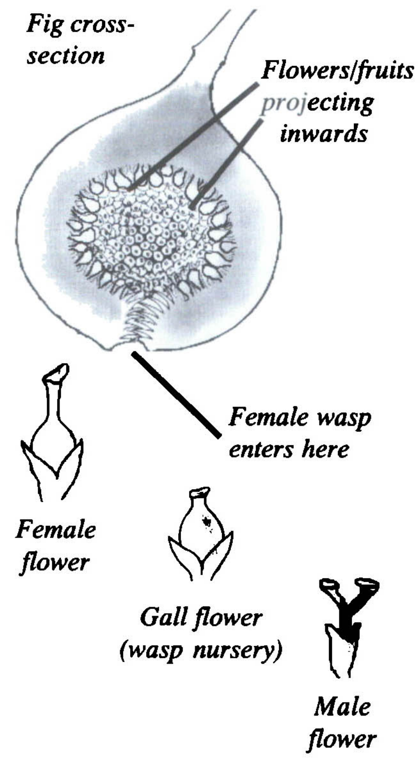
Secondly, figs are an essential food for a wide range of seed-dispersing animals, including many species of birds and bats, as well as primates, civets, squirrels, bears, deer and wild pig. One species (*F. subincisa*) produces figs in the first year after planting out, whereas most others do so by around 6 years after planting. In tropical ecology, *Ficus* species are well-known as "keystone species" *i.e.* their figs sustain populations of fruit-eating animals, when other foods are scarce. Thus, they help to maintain viable populations of seed-dispersers, which are vital for recovery of tree species richness in regenerating forest. Fig trees also seem to be fairly resistant to insect attack.

How are saplings grown?

Cut figs from *Ficus* trees when they are fully ripe (*i.e.* when birds or squirrels begin to feed on them). Break open figs and scrape out the tiny, light brown, fruits (achenes), each of which contains a single seed. Drop achenes into water and select the viable ones, which sink. Spread them out on paper and leave them to dry in the sun for 1-2 days; then sow them sparsely into

SEED COLLECTION	GP (%)	MLD (Days)	SURVIVAL	GROWTH	NOTES
Oct-Mar	60-90	25-58	E	A	Shades out weeds. Resilient after fire. Attractive to animals from 2-3 y after planting.
Nov-Jan	>80	49-67	E	E	Figs from 6th year. Attractive to animals from 2nd year. Dense crown shades out weeds well.
Aug	>90	15	E	A	
Dec-Feb	>60	16	A	E	Figs from 6th year after planting. Very attractive to seed-diseprsing birds.
Dec-Jan	70-80	39	E	E	Excellent weed suppressor, but slow to produce figs.
Sep	>35	19	A	E	Often colonizes deforested sites naturally.
May	>90	18	E	A	Figs from 3 y after planting. Excellent weed suppressor. Resilient after fire.
Aug	74-85	22	E	E	Figs from 6 y after planting.
Feb	80-90	20-27	E	E	Excellent weed suppressor. Resilient after fire. Figs from 4 years after planting. Attractive to animals from 2 years after planting.
Dec-Mar	>80	52	M	E	Figs prolifically from 3rd year after planting.
Aug	>70	50-60	E	E	Figs from 1st year after planting. Very attractive to animals.
Nov-Feb	>80	36	M	E	Figs from 4.5 years after planting.

E=excellent; A=acceptable; M=marginal



germination trays, containing a mix of forest soil and sand (50:50). Fig seedlings are tiny and prone to damping-off. Forest soil provides microbes that may help seedlings resist damping-off. Apply a fungicide (Captan) to the soil sur-face when seeds are sown and again 1 month afterwards. Place germination trays in light shade. GPs typically high (often >80%); MLDs usually short (15-60 days, depending on species).

Seedlings of most species must be grown for 5-10 months before they are robust enough for pricking-out. After potting, saplings of most *Ficus* species grow rapidly, but most are not ready for planting until the 2nd planting season after germination (TNT 18-22 months). Consequently, propagation by cuttings has been recommended to produce planting stock within a year. The method described in Box 6.2 works well with *F. hirta* and *F. superba* (applying IBA 3000 ppm to stimulate rooting of the former and IBA:NAA 2:1 for the latter) (Vongkamjan, 2003). Experiments with vegetative propagation of other *Ficus* species are encouraged.

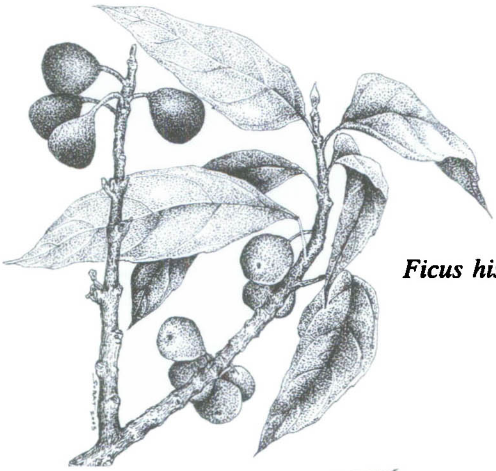
How should saplings be planted and cared for?

Some *Ficus* tree species begin life as epiphytes, growing on other trees *e.g. F. altissima.* These so-called "strangling" figs, grow a basket-like network of roots around the supporting tree, which eventually dies. When planting such species for forest restoration, do not plant them on other trees. They also grow well when planted directly into soil, provided that they do not become shaded. Most *Ficus* tree species are hardy and perform well with minimal care.

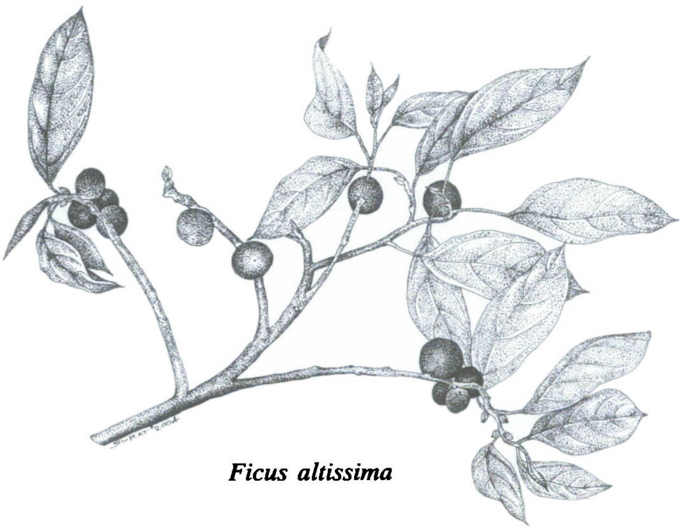
What can *Ficus* tree species be used for?

Ficus trees are rarely exploited for their wood. However, timber of a few species is sometimes used for light construction, crates, small household items and firewood. Latex has been used to make rubber, as a sealant and as a substitute for wax for dyeing batik. Medicinally, latex is applied to cover wounds. Figs of some species are edible by humans. *Ficus* tree species in general and *F. religiosa* in particular have special cultural and religious significance for Thai people, so they are unlikely to be felled.

Ficus racemosa



Ficus hispida



Ficus altissima

Ficus glaberrima

Glochidion kerrii Craib (EUPHORBIACEAE) — Krai

A shade-tolerant, understorey treelet, growing up to 7 m tall (DBH to 7 cm).

Where does it grow?

From the Himalayas, through India, S. China to Myanmar, Thailand and Indochina. In N. Thailand, it is locally common in EGF and BB-DF, at elevations of 550 to 1450 m.

What are its distinguishing characteristics?

Bark: thin, smooth, slightly flaking, light brown to grey. ***Leaves:*** alternate, simple; petiole 1-3 mm, with white, narrowly triangular stipules at base; blades ovate 2.2-9 x 1.4-4.5 cm, hairy along mid-vein on both sides. ***Flowers:*** in fascicles, light green; male flowers, 4.5-5.5 mm across; female flowers, c.2.5 mm across, 3-4 locular; February to May. ***Fruits:*** capsules, round, apically and basally flattened, 7-8 x 3.5-4 mm, becoming maroon; walls very thin; seeds, 3-6 seeds per fruit, hemispherical, 3.2-3.3 x 2.2-2.8 x 3-3.1 mm, covered in an orange-red aril; fruiting erratic, often prolonged, but mostly September to February; animal-dispersed

Why is it a framework species?

This species does not have exceptional field performance, (40-50% survival; 75 cm tall by end of 2nd rainy season), although slow growth in the first 2 years after planting accelerates markedly from the 3rd year onwards. Despite low initial performance, *G. kerrii* is worth planting because it is very effective at shading out weeds; it attracts wildlife at a young age and it adds structural diversity to the understorey. Flowering and fruiting occur in the 3rd year after planting. Many species of recruit tree seedlings establish naturally around planted *G. kerrii* trees, aged 5 years or older. This species coppices readily, providing resilience after fire (70% survival of trees burnt 21 months after planting, RCD >15 mm).

How are saplings grown?

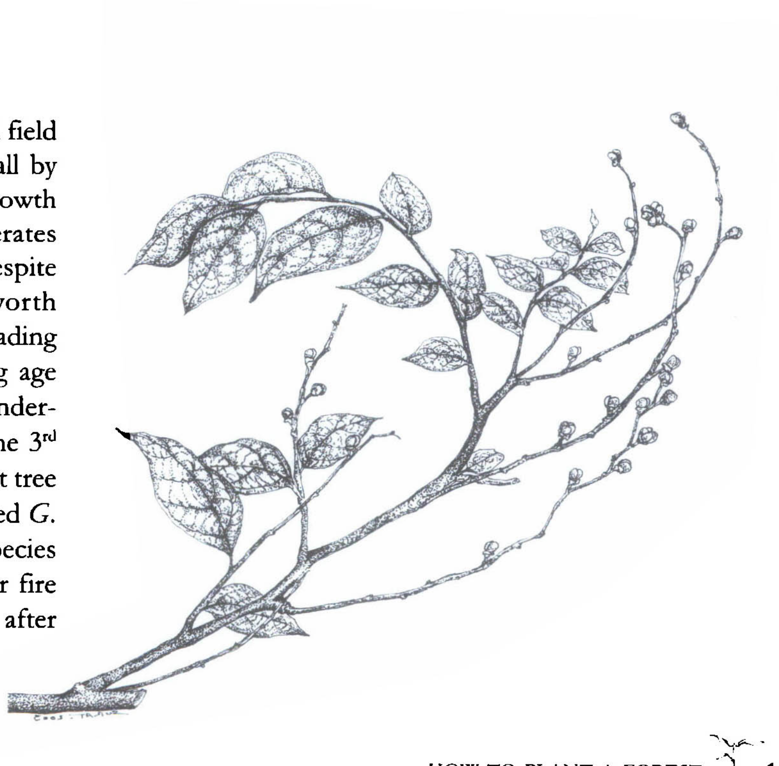
Collect ripe fruits from trees in September or October. Remove seeds from capsules. Seeds are commonly attacked by borer insects, so carry out a flotation test to remove non-viable ones. Sow seeds in trays in partial shade. GP typically 40-50%; MLD 134 days. Prick out seedlings after expansion of first true-leaf pairs. Seedling growth in containers is slow, fertilizer application is important. Saplings must be kept in the nursery until the 2nd planting season after germination (TNT 21-22 months).

How should saplings be planted and cared for?

Apply standard planting and after-care procedures (Part 7).

What can the species be used for?

Hot-burning firewood.



Gmelina arborea Roxb. (VERBENACEAE) — Saw

A briefly deciduous, pioneer tree, growing up to 30 m tall (DBH to 64 cm).

Where does it grow?

From Nepal, Pakistan, India, Sri Lanka and Myanmar across Indochina to S. China and Vietnam. In N. Thailand, this species grows sparsely in DOF, BB-DF, MXF and EGF-PINE, at elevations of 350 to 1475 m. It also establishes naturally in deforested sites.

What are its distinguishing characteristics?

Bark: thin, smooth, brown with conspicuous lenticels, becoming grey and peeling with age. ***Leaves:*** opposite, simple; blades, ovoid with pointed apex, 13-21 x 13-16 cm; upper surface dark green with 2 basal glands, lower surface silvery grey and hairy. ***Flowers:*** numerous in terminal inflorescences; flowers have 5-lobed, tubular, yellow corollas, 2.5-4.0 cm; February to March when leafless. ***Fruits:*** drupes, ovoid, yellow when ripe, averaging 26 x 18 mm, each containing a pyrene with 4 (rarely 5) chambers, of which rarely more than two contain seeds 6-9 mm long; fruiting; March to May; animal-dispersed.

Why is it a framework species?

G. arborea is an excellent framework species. Saplings survive well and grow rapidly after planting out in both lowland and upland sites, (>70% survival; 160-180 cm tall by end of 2nd rainy season). Their dense crowns shade out weeds well and support nesting birds by the 3rd year. Flowering and fruiting commence in the 5th year after planting. Fruits attract many bird and mammal species. The trees are resilient after fire (83% survival of trees burnt 21 months after planting, RCD >90 mm).

How are saplings grown?

Collect yellow fruits in April-June. Soak them in water overnight, then scrape off fruit flesh. Sun-dry the pyrenes for 1-2 days. Drop them into water and discard non-viable ones, which float. Put viable pyrenes into airtight containers with silica gel. Store at room temperature for 6 months. Sow pyrenes in mid-October in germination trays in full sunlight. Guard against seed predators. GP >60%; MLD 15-35 days. Prick out seedlings after expansion of first true-leaf pairs. Seedlings are prone to stem-boring beetles and leaf miners. Use insecticide and prune back affected tissues. Saplings ready for planting by June (TNT, excluding seed storage 8 months).

How should saplings be planted and cared for?

Do not plant this species where it is likely to become shaded. Cardboard mulch mats significantly increase survival of planted saplings. This species is prone to defoliation by beetles.

What can the species be used for?

G. arborea wood is used for pulp, plywood, and veneer; carpentry, light construction, boats, tools and carving. The wood makes good charcoal and firewood.

Heynea trijuga Roxb. *ex* Sims (MELIACEAE) — Dta Sua Toong

Synonym: *Trichilia connaroides* (Wight & Arn.) Bentv.

A small, evergreen tree, growing up to 15-20 m tall (DBH to 45 cm).

Where does it grow?

From India to Indochina, S. China, peninsular Malaysia, Sumatra, Borneo and the Philippines. In N. Thailand, it grows sparsely in MXF, EGF, and EGF-PINE, mostly above 1000 m elevation.

What are its distinguishing characteristics?

Bark: with lenticels, dark brown, shallowly cracked. ***Leaves:*** spirally arranged, imparipinnate; leaflets opposite; blades ovate or elliptic, 12-22 x 5-9 cm; margin entire or sinuous; young leaves red. ***Flowers:*** inflorescences axillary, paniculate; flowers small, numerous white or cream; February to March. ***Fruits:*** capsules, globose, thinly fleshy, dark red, 13.4 x 12.2 x 11.8 mm; septicidal with two valves, each containing 1 seed; seed glossy, black, 10.4 x 9.6 x 8.9 mm, covered in a white, fleshy aril; August to November; animal-dispersed.

Why is it a framework species?

H. trijuga is ranked as an acceptable framework species. Planted saplings achieve excellent survival rates and acceptable growth rates (>70% survival; 1-2 m tall by end of 2nd rainy season). They contribute structural diversity to the understory and shade out weeds effectively. Flowering and fruiting commence by the 3rd year after planting. Seedlings of recruit forest tree species establish around planted *H. trijuga* trees by 6 years after planting. The species is moderately resilient after fire (67% survival of trees, burnt 21 months after planting; RCD>50 mm).

How are saplings grown?

Cut ripe fruits (beginning to split) from trees in November. Remove white aril and wash seeds. Sow them in germination trays in partial shade. Germination is slow (MLD 96 days) and asynchronous, but final GP is high (up to 80%). Early seedling growth is slow, but can be accelerated by applying fertilizer. Prick-out seedlings after expansion of first true-leaf pairs. Seedlings are prone to leaf-wrinkle virus (control by sterile pruning), stem-boring flies and caterpillars. Saplings are ready for planting-out by the 2nd planting season after seed sowing (TNT 20 months).

How should saplings be planted and cared for?

Apply standard planting and aftercare procedures (Part 7).

What can the species be used for?

Timber used as firewood. Bark and leaves used in traditional Thai medicines. Fruits edible.

Hovenia dulcis Thunb. (RHAMNACEAE) — Mawn Hin

A large, briefly deciduous tree, growing up to 30 m tall (DBH to 50 cm).

Where does it grow?

From the Himalayas, to N. Thailand, China, Japan and Korea. In N. Thailand, it is a recently discovered, rare species (Maxwell, 1994) in EGF often along streams, at elevations of 1025 m to 1325 m.

What are its distinguishing characteristics?

Bark: thick, with broad, longitudinal, grey or brown ridges, separated by narrow brick-red fissures. ***Leaves:*** spirally arranged, simple; blades, thin, ovate to elliptic, 11-14 x 5-9 cm; margin serrulate. ***Flowers:*** in cymes, numerous, light green and cream, small (2.5 mm); March to May. ***Fruits:*** fruit stalks (pedicels) very thin and curving for 2-3 mm above each fruit, but further along, swollen and fleshy, green when fruits are unripe, turning red-brown or black as fruits ripen; capsules septicidal, brown or black and drying out when ripe, 7-8.5 x 6-7.5 mm, usually 3-lobed with 1 smooth, glossy, black seed (5-6 x 5-6 mm) per locule; August to February; bird-dsipersed, particularly by pigeons (Hitchcock and Elliott, 1999).

Why is it a framework species?

An excellent framework species, *H. dulcis* saplings survive well (>80% by end of 2nd rainy season) and grow rapidly (>1.5 m tall) after planting out. They develop broad crowns, which effectively shade out weeds and attract nesting birds by the 4th year. This species' deciduous habit protects it against drought. It is particularly resilient after chopping or fire (72% survival of trees burnt 21 months after planting; RCD >42 mm). *H. dulcis* fruits and the swollen axes of the infructescence are very attractive to birds, but flowering does not commence <8 years after planting.

How are saplings grown?

Cut brown or black fruits from trees in October-November (as soon as ripe). Remove seeds from capsules and drop them into water. Discard those that float. Sow seeds immediately into trays in shade (about 25% full sunlight) and protect them from rats. Germination variable, but usually synchronous. GP 50-70%; MLD 45-90 days. Water seedlings well and prick them out as soon as first true-leaf pairs expand (ideally January or February). Apply fertilizer frequently, saplings grow rapidly in containers, reaching a plantable size of 30 cm by the 1st planting season after seed collection (TNT 8-9 months).

How should saplings be planted and cared for?

This species thrives, even where aftercare procedures are neglected, but responds particularly well to fertilizer application.

What can the species be used for?

Wood is suitable for pulp and fibre. The swollen axes of the infructescence are used traditionally to alleviate hangovers.

Lithocarpus elegans (Bl.) Hatus. *ex* Soep. (FAGACEAE) Gaw Mawn

A small to medium-sized, shade-tolerant, evergreen tree, growing up to 15 to 20 m tall.

Where does it grow?

From N. India, Nepal, Pakistan and Myanmar, through Yunnan, Indochina, Thailand, peninsular Malaysia, Indonesia and Borneo. In N. Thailand, it is very common in BB-DF, MXF and EG-PINE at elevations of 450 to 1450 m. It re-establishes well in degraded DOF, protected from fire.

What are its distinguishing characteristics?

Bark: thick, vertically cracked, grey or grey-brown ***Leaves:*** spirally arranged, simple; blades elliptical to oblong, glabrous, leathery, 10-20 x 4-8 cm; margin entire. ***Flowers:*** in upright, slender clusters, males and females in separate clusters on same tree; flowers, tiny, cream coloured; March to October. ***Fruits:*** nuts, densely clustered without stalks, globose, depressed, brown when ripe, 1.5-2.5 cm, scaley cupule, with distinct rings covers less than half of fruit; July to October; animal-dispersed.

Why is it a framework species?

Planted *L. elegans* saplings achieve acceptable survival rates and excellent growth rates after planting out (56% survival; >2.2 m tall by end of 2nd rainy season). Crowns are narrow but dense and effectively shade out weeds. The nuts (particularly immature ones) are relished by squirrels, wild pigs, deer and other seed dispersers, but this species does not flower within 4 years after planting.

How are saplings grown?

Collect nuts from the ground in September. Remove cupules and drop nuts into water. Sow the viable ones (which sink) into germination trays in partial shade. Cover trays with wire mesh to prevent rats from eating the nuts. Germination, slow, asynchronous, continuing for 270 days. GP 50-70%; MLD 140 days. Prick out seedlings intermittently, after expansion of first true-leaf pairs. Early seedling growth is slow, but can be accelerated with fertilizer. Saplings are usually ready for planting by 2nd planting season after germination (TNT 21 months).

How should saplings be planted and cared for?

Apply standard planting and aftercare procedures (Part 7), except that cardboard mulch should not be used, as it significantly reduces field performance of this species.

What can the species be used for?

Timber is durable and is suitable for construction, firewood, charcoal making and mushroom culture.

Macaranga denticulata (Bl.) M. –A. (EUPHORBIACEAE) Tawng Taep

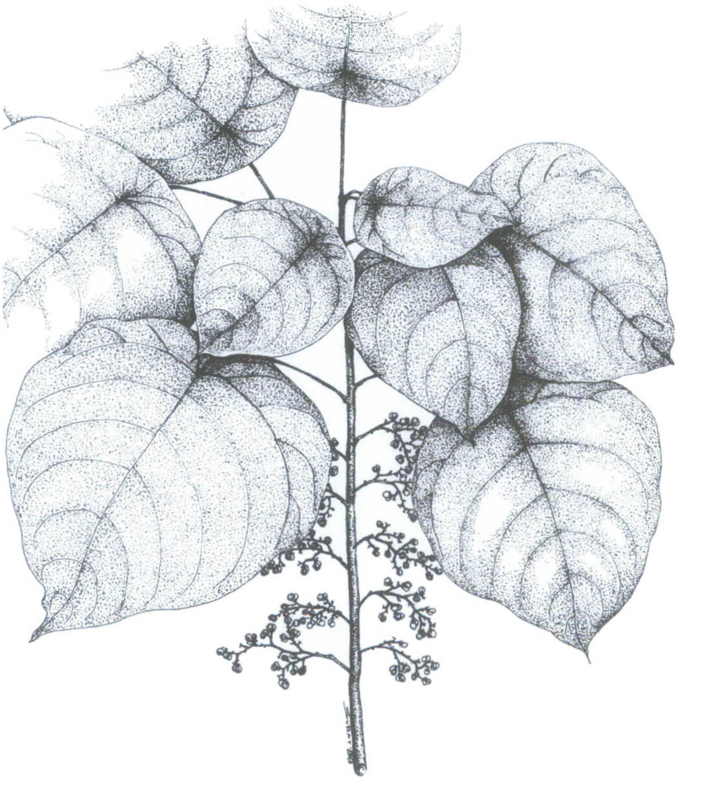
A medium-sized, pioneer, evergreen, tree, growing up to 20 m tall (DBH 40 cm).

Where does it grow?

From E. Himalayas to Sri Lanka and Indochina, S. China, Thailand, Laos, peninsular Malaysia, Sumatra and Java. In N. Thailand, it is common in disturbed forest areas and secondary growth in EGF, MXF and BB-DF, often along roadsides and river banks at elevations of 500 to 1400 m.

What are its distinguishing characteristics?

Bark: thin, light brown, cracked, with pustular lenticels. ***Leaves:*** spirally arranged, simple; petiole red; blades peltate. ***Flowers:*** unisexual; males in small panicles, globose, about 6 per cluster; females in dense racemes; March to August. ***Fruits:*** capsules, septicidal, smooth, light brown to blackish brown on ripening, 3-5 x 5-6 mm; seeds, 1 per locule, globose, black, 3-4 x 3-4 mm; July to December; dispersed by birds and small mammals.



Why is it a framework species?

An excellent framework species, *M. denticulata* establishes well on degraded land. On average, it grows taller than 2.5 m, by the end of the 2nd growing season after planting and taller than 4 m by the end of the 4th. Its large leaves form a dense crown (>4 m broad by 4th growing season), which shades out weeds very effectively. It can flower by the 2nd year after planting and its fruits attract seed-dispersing birds. Tapirs relish the leaves.

How are saplings grown?

Collect fruits in October, when they start to split. Sun-dry them, clean off sticky coating from seeds, then sun-dry the seeds for a further 1-2 days. After that, place seeds in concentrated sulphuric acid for 2 minutes, wash off acid and sow seeds shallowly in trays in sunlight. Germination is rapid and synchronous; GP 90%; MLD 19 days. Prick out seedlings when the first true leaf pairs expand. If black-spot fungus is seen on shoots, destroy infected plants and spray healthy ones with fungicide. Saplings can be planted when 30 cm tall *i.e.* by the 1st planting season after seed collection (TNT 9 months).

How should saplings be planted and cared for?

This species has delicate saplings, which must be handled carefully to prevent high post-planting mortality. It responds well to cardboard mulching, but is not particularly fire-resilient; so only plant it where fire prevention is effective.

What can the species be used for?

Timber can be used for temporary and light construction and packing cases. On fallow fields, dense stands of *M. denticulata* enrich the soil and increase rice yields, when the fallow is subsequently cleared for rice cultivation.

Machilus kurzii King *ex* Hk.f. (LAURACEAE)

Tong Hawm

An medium-sized evergreen tree or treelet, growing approximately 15 m tall (DBH 60 cm).

Where does it grow?

From India to S. China (Tibet, Yunnan) and Indochina. In N. Thailand, it is common in MXF, EGF and EGF-PINE, often in secondary growth, at elevations of 550 to 1550 m.

What are its distinguishing characteristics?

Bark: brown, cracked. ***Leaves:*** spirally arranged, simple; blades lanceolate or narrowly elliptic, thin, leathery, smooth, tapering at both ends; midrib prominent on lower part of blade. ***Flowers:*** in long clusters, small, white-cream; February to April. ***Fruits:*** drupes, ovoid, glossy black on ripening; persistent calyx; seed, one per fruit, 6 x 7 mm; June to September; animal-dispersed.

Why is it a framework species?

M. kurzii saplings survive well and grow rapidly after planting out (>65% survival; averaging >1.8 m tall by end of 2nd rainy season). They develop acceptably broad crowns, which are moderately effective at shading out weeds. Flowering and fruiting commence in the 3rd year after planting and the fleshy fruits attract seed-dispersing animals. Birds use this species for nesting from the 5th year after planting. *M. kurzii* seedlings commonly establish naturally in 5-6 year-old framework species plots.

How are saplings grown?

Collect fallen, black fruits in July. Remove fruit flesh, drop seeds into water and discard non-viable ones, which float. Air-dry the seeds; then sow them in germination trays in shade. Germination is asynchronous. GP often low (c.30%), so collect more seeds to compensate; MLD 108-178 days. Prick out seedlings intermitently, after expansion of first true-leaf pairs. Saplings grow slowly and are not ready for planting until the 2nd planting season after seed collection (TNT 23 months). More research is needed to accelerate sapling production.

How should saplings be planted and cared for?

Apply standard planting and after-care procedures (Part 7), but continue weeding into the dry season.

What can the species be used for?

An excellent firewood. In India it is semi-domesticated to produce leaves fed to silk worms (*Antherea assama*), which produce golden yellow silk.

Magnolia baillonii Pierre (MAGNOLIACEAE)

Jahmbee Bah

Synonyms: *Michelia baillonii* (Pierre) Fin & Gagnep., *Paramichelia baillonii* (Pierre) Hu

A large, briefly deciduous tree, growing up to 35 m tall (DBH to 1 m).

Where does it grow?

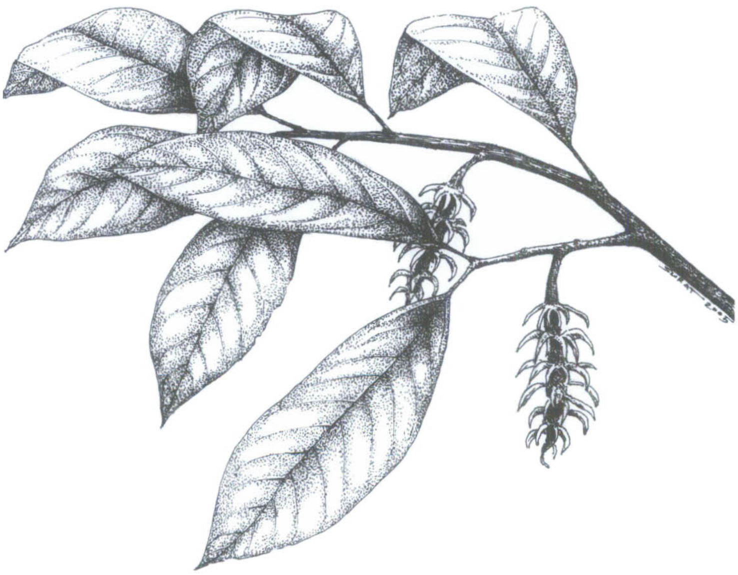
Yunnan and Indochina (Myanmar, Thailand, Cambodia, Vietnam). In N. Thailand, it grows at medium abundance in MXF and EGF, at elevations of 650 to 1350 m.

What are its distinguishing characteristics?

Bark: thick, brown, flaking, longitudinally cracked. ***Leaves:*** spirally arranged, simple; blades elliptic, ovate-elliptic, or lanceolate, 6-22 x 4-8 cm. ***Flowers:*** solitary, axillary, fragrant; tepals 18-21, 6 per whorl, cream; June to October. ***Fruits:*** aggregates of capsules, 6-10 x 4-5 cm; mature carpels fall off irregularly, leaving behind the vascular framework; seeds black, 9 x 2 mm, with bright red-orange arils; March to August; dispersed by birds.

Why is it a framework species?

M. baillonii is an excellent framework species. Planted saplings achieve acceptable survival rates and excellent growth rates (averaging >65% survival and >2 m tall by end of 2nd rainy season). Their broad crowns (>1.5 m) suppress weed growth well. Fragrant flowers attract insects and birds eat the seeds, but flowering has not been observed <5 years after planting. This species recovers well after burning (>70% survival of trees burnt 21 months after planting; RCD >5 cm). *M. baillonii* establishes naturally in framework species plots 5 years or older.



How are saplings grown?

Cut fruits from trees in July-August, just as parts of the fruits are beginning to fall. Soften the fruits in water, then remove the seeds. Rub off the red-orange arils and soak seeds in water for 24 h. Remove any non-viable ones, which float. Sun-dry seeds for 1-2 days, then sow them shallowly in trays in sunlight in 1:1 forest soil:sand to prevent damping-off. Protect trays from rodents. Germination is slow and asynchronous. GP c. 30%; MLD 100 days. Prick out seedlings after expansion of first true-leaf pairs. If aphids are observed attacking this species, destroy infested plants and spray survivors with insecticide. Containerized plants grow rapidly in the nursery and are usually ready for planting by the 1st planting season after seed collection (TNT 11 months).

How should saplings be planted and cared for?

This species responds very well to cardboard mulch placed around trees at planting time.

What can the species be used for?

Timber can be used for construction and furniture. Its fragrant flowers make *M. baillonii* a popular garden tree.

Manglietia garrettii Craib (MAGNOLIACEAE)

Monta Daeng

A medium-sized, evergreen or leaf-exchanging tree, up to 20 m tall (DBH to 41 cm).

Where does it grow?

From S. China and Thailand to Vietnam. In N. Thailand, this species grows at medium abundance in primary EGF at elevations of 1050 to 1600 m.

What are its distinguishing characteristics?

Bark: thin, smooth, grey, becoming markedly pustular-lenticellate. ***Leaves:*** spirally arranged, simple; blades leathery, elliptic to obovate, 18-34 x 8-12; stipules large, hairy; stipule scars on stems prominent after leaf fall; petioles 3-5 cm with brown hairs. ***Flowers:*** terminal, solitary, bisexual, 5.5-6.5 cm long; tepals 9, dark pink-purple; peduncle 1.5-4 cm long; stamens and carpels numerous; March to April. ***Fruits:*** aggregates of many capsules, light yellow-green when unripe, maroon to brown and woody when ripe, 95 x 60 mm; seeds, one per capsule, black, 10 x 4 mm, covered in a red aril, attached to fruit by thin thread; September to November; seeds dispersed by birds.

Why is it a framework species?

M. garrettii is a marginally effective framework species, but can be planted on ex-EGF sites to add structural diversity to the forest canopy. Planted saplings survive poorly (c. 50%), but survivors grow well (c.1.5 m and >5 m tall by end of 2nd and 5th rainy seasons respectively), developing broad, dense crowns, which effectively shade out weeds. *M. garrettii* seeds attract birds and squirrels, but fruiting does not commence within 7 years after planting. Nevertheless, younger trees do attract seed-dispersing wildlife, since seedlings of several animal-dispersed tree species establish around *M. garrettii* crowns by the 6th year after planting.

How are saplings grown?

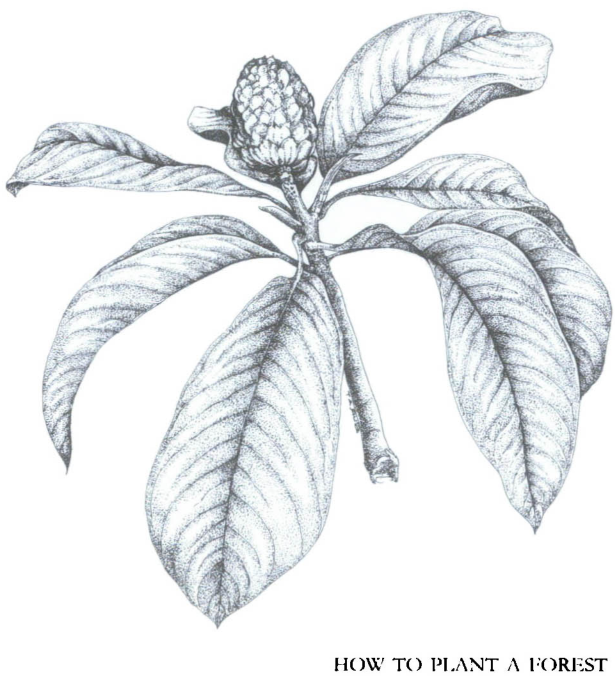
Collect fruits, as they start to split open, in October (cut from trees). Sun-dry them and remove the seeds. Rub off the red aril and drop the black seeds into water. Discard non-viable ones, which float. Sun-dry seeds for 1 day, then sow them in in trays in partial shade. Protect seeds from squirrels and rats. Germination is usually slow and asynchronous. GP 65-75%; MLD 47-81 days. Prick out seedlings after expansion of first true-leaf pairs. Containerized saplings grow large enough for planting out (*i.e.* 50 cm) by the 2nd planting season after seeds are sown (TNT 20 months).

How should saplings be planted and cared for?

Planted *M. garrettii* saplings respond well to placement of cardboard mulch at planting time and frequent fertilizer application. More research is needed to increase post-planting survival rates.

What can the species be used for?

Lightweight hardwood, for construction, furniture, veneer, plywood and carving.



Melia toosendan Sieb. & Zucc. (MELIACEAE) — Lien

A medium-sized, briefly deciduous, pioneer tree, growing up to 25 m tall (DBH to 47 cm).

Where does it grow?

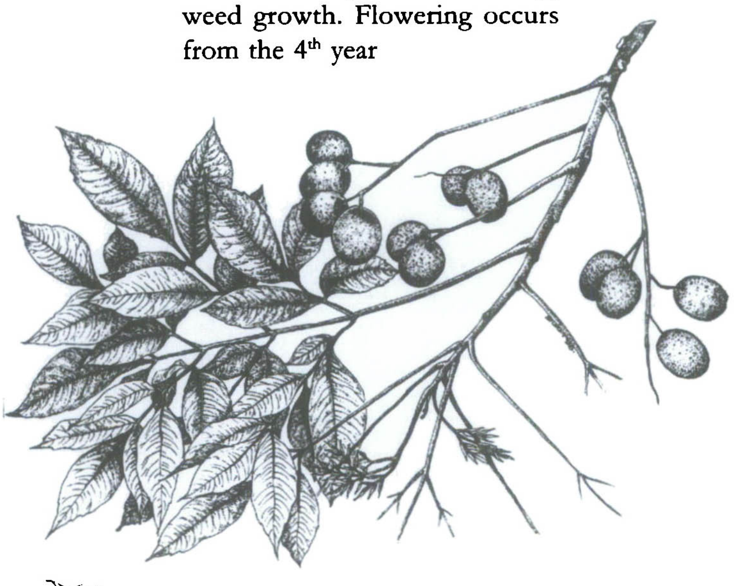
From Myanmar, through N. Thailand, Indochina, S. China and Japan. In N. Thailand, it is characteristic of secondary growth in EGF and MXF, at elevations of 700 to 1450 m.

What are its distinguishing characteristics?

Bark: thin, grey-brown, with shallow fissures. ***Leaves:*** spirally arranged, doubly pinnate or tripinnate; leaflet blades ovate, 3-7 x 1-2 cm, with acuminate tip, margin often toothed. ***Flowers:*** inflorescences axillary and paniculate; flowers numerous, corllas white (c.10 mm); January to March. ***Fruits:*** drupe, yellow when ripe, 25 x 22 mm; ridged, woody pyrene contains up to 5 seeds; seeds black, 6 x 3 mm; October to March; animal-dispersed.

Why is it a framework species?

An excellent framework species, *M. toosendan* is the fastest growing tree species tested by FORRU so far. Planted saplings achieve survival rates of >90% and grow 5-7 m tall by end of 2nd rainy season. They develop very broad crowns (>2.5 m), which contribute substantially to forest canopy cover and suppress weed growth. Flowering occurs from the 4th year after planting and fruiting from the 5th. Barking deer eat the fruits. This species is very attractive to birds, with 24 species recorded as regular visitors, including 5 bulbul species, which are important seed-dispersers. Its fragrant flowers attract many insects. It is highly resilient after burning (70-100% survival of trees burnt 21-33 months after planting; RCD >5 cm).



How are saplings grown?

Collect yellow fruits from the ground in October-November. Sun-dry them, then crack open the woody pyrenes with a knife to remove the seeds. Sow seeds shallowly in sunlight in 1:1 forest soil and sand to prevent damping-off. Germination is rapid. GP 70%; MLD 15 days. Prick out seedlings after expansion of first true-leaf pairs (ideally in January). Take precautions against caterpillars and fungal infection and do not prune or apply fertilizer (except if symptoms of nutrient deficiency develop). Saplings grow rapidly to 30 cm tall (ready for planting) by the 1st planting season after seed collection (TNT 7-8 months). Harden them in sunlight and reduce watering 6 weeks before planting.

How should saplings be planted and cared for?

Saplings are delicate and require extreme care during transportation. *M. toosendan* grows well with minimal aftercare, but it is particularly responsive to cardboard mulching. Excellent results have been achieved with direct seeding.

What can the species be used for?

The timber is used as firewood. The fruit extract is an insecticide and is used as Chinese medicine. It is an analgesic, anti-helminthic, anti-fungal and anti-inflammatory, but therapeutic doses are close to toxic doses. Consumption of 5-6 fruits can be lethal to adult humans.

Nyssa javanica (Bl.) Wang. (NYSSACEAE) — Kang Khak

A large, evergreen or leaf-exchanging tree, growing 30-40 m tall (DBH to 90 cm).

Where does it grow?

From India and Myanmar to Thailand, Indochina and south to peninsular Malaysia, Sumatra, Java and Borneo. In N. Thailand, it is common in EGF and MXF, especially along streams at elevations of 550 to 1400 m.

What are its distinguishing characteristics?

Bark: thick, vertically cracked, often flaking, brown-grey. ***Leaves:*** spirally arranged, simple; blades elliptic to oblong, 13-22 x 6-12 cm; young ones covered in dense silvery hairs; no stipules. ***Flowers:*** inflorescences axillary; male and bisexual on different trees; flowers tiny, yellow-green; February to April. ***Fruits:*** drupe, ovate, juicy, dark red-orange when ripe, 18-20 x 12-15 mm; pyrene contains single seed; seed light brown, flattened, 15 x 8-10 mm, covered by a red aril; April to August; animal-dispersed.

Why is it a framework species?

N. javanica is ranked as an acceptable framework species. Planted saplings have rather low survival rates, but excellent growth rates after planting out in deforested sites (c. 50-60% survival; 2-2.8 m tall by end of 2nd rainy season). They develop dense, broad crowns (>160-200 cm across), which shade out weeds. Birds favour the trees as perching sites and the fleshy fruits of mature trees are eaten by birds and mammals. Although fruiting does not occur until >7 years after planting, younger trees are attractive to seed-dispersing wildlife, since seedlings of several animal-dispersed tree species establish beneath *N. javanica* crowns by the 6th year after planting.

How are saplings grown?

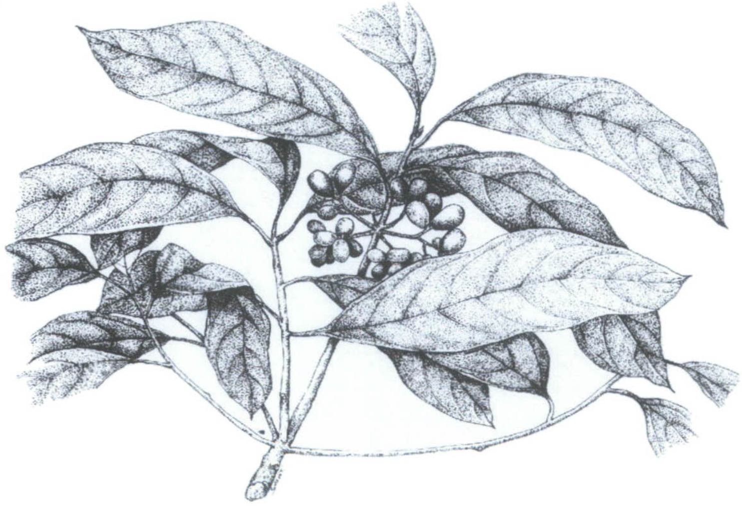
Collect fallen fruits in August or September. Rub fruits on a sieve to remove the fruit flesh and scrape off the aril under running water. Sow seeds in trays in 1:1 forest soil:sand to prevent damping-off. If damping-off does occur, remove and destroy infected seedlings and spray survivors with fungicide. Protect sown seeds from predation by rats. Germination is asynchronous and prolonged (up to 100 days). GP typically c.70%; MLD 40 days. Prick out seedlings after expansion of first true-leaf pairs. Saplings grow rapidly and are usually large enough for planting out by the 1st planting season after seed collection (TNT 9-10 months).

How should saplings be planted and cared for?

This species responds well to cardboard mulching and vigorous weeding into the early dry season. It is not very resilient after burning, so plant it where fire prevention is effective.

What can the species be used for?

Timber is dense and is suitable for house construction, furniture, packing cases, veneer and plywood. Fruit is edible.



Peltophorum dasyrhachis (Miq.) Kurz Nonsi Bah or Arang (Leguminosae, Caesalpinioideae)

A small to medium-sized, light demanding, deciduous tree, growing up to 30 m tall.

Where does it grow?

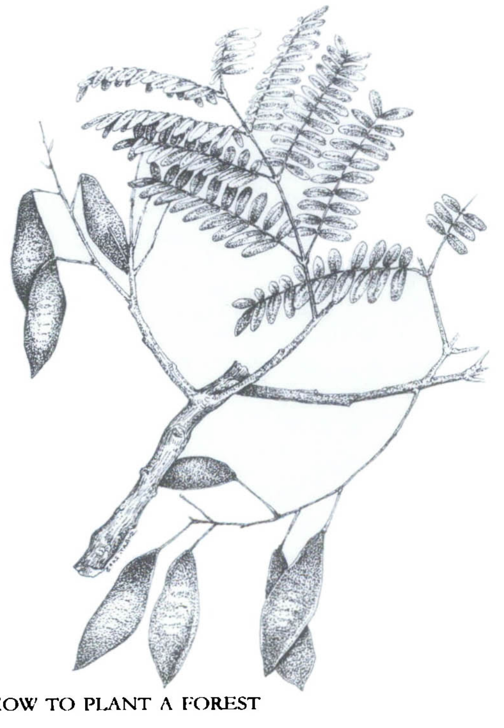
From Indochina (Thailand, Cambodia, Laos and Vietnam) to Malaysia and Indonesia. In central and SW. Thailand, it grows in degraded areas in BB-DF and lowland EGF at elevations of 80 to 900 m.

What are its distinguishing characteristics?

Bark: smooth, brown. ***Leaves:*** doubly pinnate, 18-25 cm long; large pectinate stipules at bases of petioles. ***Flowers:*** in unbranched, axillary clusters 5-35 cm long; petals bright yellow, 1.5-2 cm across; March to April. ***Fruits:*** pods, indehiscent, elliptical, tapering at both ends, dull brown on ripening, 10-15 x 2-3.5 cm; 4-5 flat seeds per pod; fruiting October-January; pods wind-dispersed.

Why is it a framework species?

P. dasyrhachis is an acceptable framework species for restoring both deciduous and evergreen forest types, in central or SW Thailand; particularly highly degraded sites or those with saline soils. Although survival rates can be low, planted saplings achieve acceptable growth rates and develop dense crowns, which shade out weeds. Their nectar-rich flowers attract insects, birds and squirrels. Being a legume, it can increase the nitrogen content of the soil and is suitable for agro-forestry.



How are saplings grown?

Collect brown pods from trees in September or October. Sun-dry them until they split open and release the seeds. Soak the seeds in water overnight. Sow those that begin to swell and discard any non-viable ones, which float. Sow seeds shallowly in germination trays in full sunlight. Prevent seed predation by covering trays in wire mesh. Germination is usually low GP c.42%; MLD 84 days. Prick out seedlings once the first true leaf pair has expanded. Containerized saplings grow slowly and are not large enough for planting out until the 2nd rainy season after seed collection (TNT 21 months).

How should saplings be planted and cared for?

Use standard planting procedures described in Part 7. This species responds well to cardboard mulching.

What can the species be used for?

This species is useful as a shade tree and as a fallow crop due to its nitrogen fixing properties. Timber can be used for firewood. The bark and wood of *P. dasyrachis* are used to make a red or yellowish brown dye. Its flowers are important for honey bee culture. Tolerant of saline soils. Intercropped with maize in agroforestry systems.

Prunus cerasoides D. Don (ROSACEAE)

Nang Paya Sua Krong

A medium-sized, pioneer, deciduous tree, growing up to 16 m tall (DBH to 38 cm).

Where does it grow?

From the Himalayas and S. China to Myanmar and N. Indochina. In N. Thailand, it is rare in EGF, MXF and EGF-PINE, often in disturbed areas, at elevations of 1040 to 2400 m.

What are its distinguishing characteristics?

Bark: shiny, red-brown, with large, raised, brown lenticels; outer layer peeling horizontally. ***Leaves:*** spirally arranged, simple; blades 9-12 x 3-5 cm; margin finely serrate; 1-2 dark red, stalked, glands where petiole meets blade. ***Flowers:*** in axillary clusters, 1-2.5 cm across, petals, 5, pink; on leafless trees December to January. ***Fruits:*** drupes (small cherries), ovoid, red when ripe, 1-1.5 cm, each containing a single-seeded pyrene; March to May; dispersed by birds, squirrels and other small mammals.

Why is it a framework species?

P. cerasoides is an excellent framework species. Planted saplings survive very well and grow rapidly when planted out (>80% survival and >3 m tall by end of 2nd rainy season). They develop broad crowns (>2.4 m across), which effectively shade out weeds and they flower, fruit and provide bird nest sites by the 3rd year after planting. Birds such as, Sunbirds, Spiderhunters and White-eyes feed on the nectar, whilst bulbuls eat the fruits.

How are saplings grown?

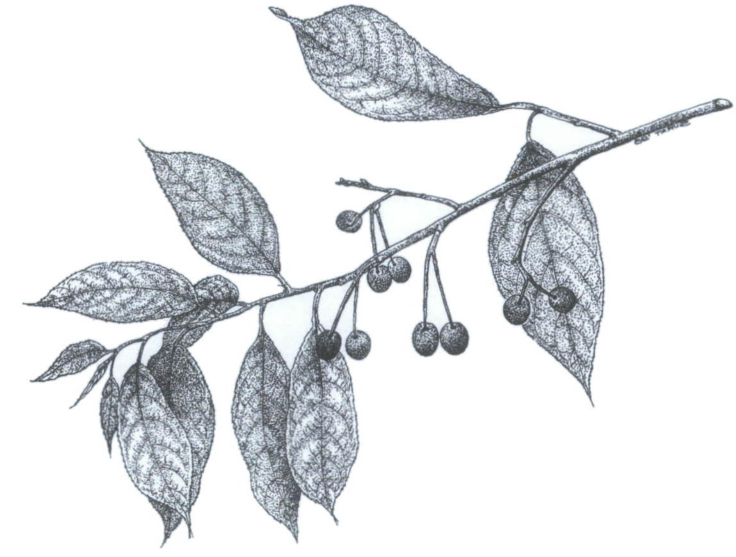
Collect ripe fruits mid-March. Scrape off the fruit pulp with a knife, under running water to expose the woody pyrene. Sun-dry the pyrenes. Place them in airtight containers with silica gel for 2 days, then change the silca gel and store the containers in a refridgerator at 5 degrees centigrade. The following January, take the pyrenes out of storage and sow them in germination trays in full sunlight. GP typically >70%; MLD 48-52 days. Prick out seedlings when they are 5-7 cm tall, with 4-5 leaves (usually 7-10 days after germination). Apply no fertiliser, unless nutrient defidiency symptoms develop and if necessary, prune the plants to prevent them from outgrowing their containers. Saplings are ready for planting, when 30 cm tall (TNT 5 months, excluding seed storage).

How should saplings be planted and cared for?

P. cerasoides responds well to cardboard mulching, repeated for two years. The species is also suitable for direct seeding. Prepare and store pyrenes as described above, then sow them directly into deforested sites at the beginning of the rainy season. (see Part 4).

What can this species be used for?

Wood used for construction, furniture, cabinet-work, interior finish and firewood. Leaves for fodder. A popular ornamental tree in gardens and along roadsides. Plantations have been established in Nepal.



Quercus semiserrata Roxb. (FAGACEAE)

Gaw Dtah Mu Luang

Synonym: *Cyclobalanopsis semiserrata* (Roxb.) Oersted

A large, evergreen tree, growing up to 30 m tall (DBH to 1 m).

Where does it grow?

From India, Bangladesh, Myanmar and S. China to Indochina. In N. Thailand, it is common in EGF, MXF and EGF-PINE, at elevations of 800 to 1675 m.

What are its distinguishing characteristics?

Bark: thick, grey-brown, vertically cracked. ***Leaves:*** spirally arranged, simple; blade ovate-oblong, glabrous, leathery, 13-25 x 3-8 cm; margin serrate towards the apex. ***Flowers:*** in axillary unisexual clusters, male flowers light yellow, female flowers light green, maturing to yellow; March to April. ***Fruits:*** nut, oblong-oval, hairy, 3.5-4 x 2 cm; cupule encloses lower third; one seed per nut; masting December to July, every 2-3 years; animal-dispersed.

Why is it a framework species?

Planted *Q. semiserrata* saplings achieve high survival and growth rates (>70% survival and averaging 115 cm tall by end of 2nd rainy season). Branching occurs near the base within the first year and trees develop a dense but narrow crown, which effectively shades out weeds and supports birds' nests from the 2nd year after planting. Fruiting can occur as early as 1.5 years after planting, but this is very rare. Most trees do not flower until the they are >5 years old. Squirrels and wild pigs eat the nuts.

How are saplings grown?

Collect nuts as they begin to fall from the trees (ideally June-July). Remove cupules and drop the nuts into water. Remove the non-viable ones which float. Sow nuts on their side, 2-3 cm apart, directly into deep containers (to prevent root deformities after germination), in partial shade. Germination is reliably high and synchronous. GP 85-92%; MLD 18 days. Leaf pruning once in the first 6 months may increase sapling growth rates. Saplings usually grow large enough for planting out by the 1st planting season after seed collection (TNT 11-12 months).

How should saplings be planted and cared for?

This species grows better in partially shaded conditions. Allow weeds to grow up around planted trees towards the end of the rainy season, so that they shade the young trees during the dry season. Do not apply cardboard mulch. *Q. semiserrata* does not survive well after fire, so only plant it where fires are effectively excluded.

What can the species be used for?

Timber for construction, posts, beams, agricultural tools, furniture, interior finish and firewood. It is also used for mushroom cultivation. Leaves used to raise silk worms in India.

Rhus rhetsoides Craib (ANARCARDIACEAE) — Gawk Gun

A medium-sized, pioneer, deciduous tree, growing up to 25 m tall (DBH to 30 cm).

Where does it grow?

N. Vietnam and N. Thailand. In N. Thailand, it is moderately common in EGF, MXF and EGF-PINE, at elevations of 650 to 1550 m.

What are its distinguishing characteristics?

Bark: cracked, brown-grey, with brown lenticels; sap causes skin rashes. ***Leaves:*** spirally arranged, pinnate; leaflets in 4-5 opposite pairs plus terminal one; leaflet blades, lanceolate to oblong, 9-15 x 2.5-5 cm; margin entire or sinuous. ***Flowers:*** inflorescences axillary, open paniculate, 30-45 cm long; flowers unisexual and bisexual, 1.5 mm long, light yellow-greenish; July to August. ***Fruits:*** drupe asymmetrically ovoid, dark brown on ripening, 8 x 5 x 3 mm; mesocarp thin, almost dry; pyrene contains a single seed; seed brown and flattened, 3 x 2.5 x 0.5 mm; September to December; dispersed by squirrels and birds.

Why is it a framework species?

R. rhetsoides is an excellent framework species. Planted saplings achieve very high survival and growth rates (>80% survival and averaging >3 m tall by end of 2nd growing season). Although, this species develops only a moderately broad crown, it effectively suppresses weed growth. It withstands moderate fires well (>90% survival of trees burnt 21 months after planting; RCD >80 mm). Prolific flowering and fruiting from the 2nd year after planting attracts many seed-dispersing animals as well as nesting birds.

How are saplings grown?

Use gloves when handling fruits of this species as they may cause an allergic reaction. Collect dark brown fruits from trees from September to October. Remove the thin covering from the pyrenes and drop them into water. After discarding non-viable pyrenes, which float, sun-dry remaining ones and sow them in trays in full sunlight. GP typically 50-60%; MLD 24 days. Germination is asynchronous, so prick out intermitently as seedlings expand their first true-leaf pairs. Take precautions against aphids and fungal, die-back diseases, which attack young seedlings in the cool season. Water the seedlings well. Use a nutrient-rich medium, or apply fertilizer frequently, to ensure saplings grow tall enough by the 1st planting season after seed sowing (TNT 8-9 months).

How should saplings be planted and cared for?

This species thrives in hot, dry, sunny conditions, even on degraded sites. Weed frequently and into the start of the dry season. Responds well to cardboard mulching.

What can the species be used for?

The sap can be used for making lacquer-ware.

Sapindus rarak DC. (SAPINDACEAE) — Mah Sak

A medium-sized, light-demanding, deciduous tree, growing up to 25 m tall (DBH 25 cm).

Where does it grow?

In India (Assam), Myanmar, Indochina, and Indonesia. In N. Thailand, it is common in EGF and MXF, often on disturbed sites or along streams, at elevations of 625 to 1620 m.

What are its distinguishing characteristics?

Bark: grey or light brown, becoming fissured with age. ***Leaves:*** spirally arranged, paripinnate, 38-44 cm long; leaflets 8-10, mostly opposite; leaflet blades asymmetrically lanceolate to oblong, 7-13 x 2.5-3.5 cm. ***Flowers:*** inflorescences terminal, 23-35 cm long; flowers numerous, bisexual, 4 mm long, petals white; March to April. ***Fruits:*** drupes, globose, leathery and wrinkled; yellow-brown when ripe, 25 x 23 mm; seed, one per drupe, black 16 x 15 mm; July to January; animal-dispersed.

Why is it a framework species?

S. rarak is an acceptable framework species. Planted saplings achieve excellent survival rates and acceptable growth rates (c.80% survival; averaging 1.25 m tall, by end of 2nd rainy season). Despite a narrow crown, the species effectively suppresses weed growth. It fruits prolifically, but takes longer than 7 years before fruiting commences. Its fruits are eaten by wild pigs and deer. This species survives moderate fires and regenerates well after burning (100% survival of trees burnt 33 months after planting; RCD >10 mm).

How are saplings grown?

Cut fruits from trees as soon as ripe ones are first seen (ideally August). Remove fruit flesh. Put pyrenes in water and discard non-viable ones, which float. Sow those that sink, in germination trays in full sunlight. GP usually >80%; MLD 45-52 days. Germination is asynchronous, continuing for >130 days. Prick out seedlings at frequent intervals after expansion of first true-leaf pairs. If fertilizer is applied, containerized saplings usually grow tall enough for planting out by 1st planting season after seed collection (TNT 10 months).

How should saplings be planted and cared for?

Standard planting and after-care procedures (Part 7), with cardboard mulching, usually yield good results. *S rarak* grows best in moist but sunny locations. If surrounded by faster-growing tree species, shade suppresses growth. It is susceptible to attack by white aphids.

What can the species be used for?

Saponins, from the fruits, are used to make soaps and shampoos and have antibacterial properties. The fruits are also used to make insecticides. *S. rarak* wood can be used for general construction and furniture, but it is not durable. Seeds can be used for buttons or beads.

Sarcosperma arboreum Bth. (SAPOTACEAE) — Mah Yang

A medium-sized, shade tolerant, evergreen tree, growing up to 25 m tall (DBH to 50 cm).

Where does it grow?

In S. China, NE. India, Myanmar and Thailand. In N. Thailand, it is common in EGF and MXF, at elevations of 650 to 1400 m.

What are its distinguishing characteristics?

Bark: greyish brown, thin, flaking with shallow fissures; sap white. ***Leaves:*** opposite or sometimes alternate; blades oblong, 10-26 x 4-8 cm; both surfaces glabrous. ***Flowers:*** in panicles; small 2-4 mm, sepals rust-coloured, corolla yellow; December to February. ***Fruits:*** drupes, purple-black when ripe, oblong, 15-25 x 7-15 mm; seeds, 1 per fruit, light brown or cream, 18 x 12 mm; fruiting April to August; animal-dispersed.

Why is it a framework species?

S. arboreum is an excellent framework species. Planted saplings acheive very high survival rates and acceptable growth rates (>70% survival; >100 cm tall by end of 2nd rainy season), although their narrow crowns do not suppress weed growth very well. Flowering and fruiting commence in the 5th year after planting. Several bird species and barking deer eat the fruits. This species regenerates well after moderate fires (>80% survival of trees burnt 33 months after planting; RCD >22 mm).

How are saplings grown?

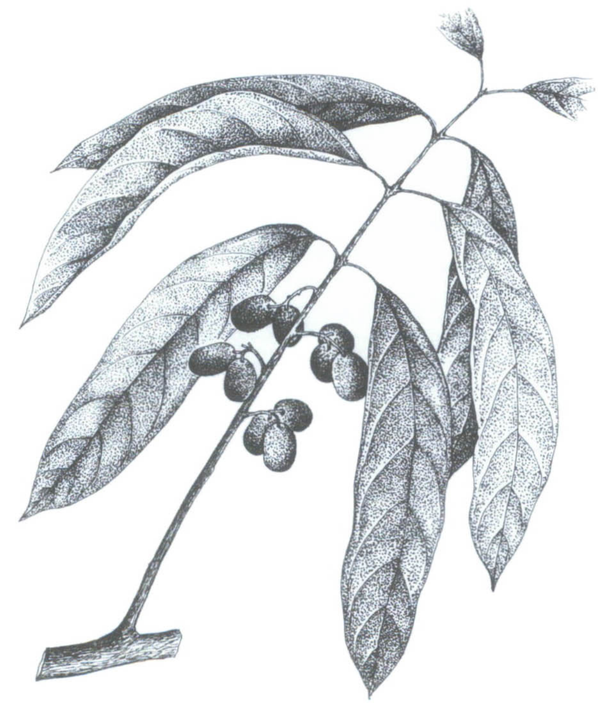
Collect fallen, blackish-purple fruits in July. Remove fruit flesh and clean the seeds. Place seeds in water and discard the non-viable ones, which float. Air-dry the seeds, then sow them directly into plastic bags or root trainers, using standard potting mix. Place containers in shade, water them frequently and protect them from rats and squirrels, which like to eat the seeds. GP c.60%; MLD 60-67 days. Saplings usually grow slowly and are not large enough for planting out until the 2nd planting season after seed collection (TNT 23 months). To produce plantable trees within a year, experiment with increased fertilizer application or cultivating wildlings (see Box 6.1).

How should saplings be planted and cared for?

S. arboreum should be planted in fairly shady, moist sites. Apply standard planting and aftercare procedures (Part 7). As it has poor weed suppression capabilities, weeding around *S. arboreum* trees may have to be continued for longer than usual. Successful results have been achieved with direct seeding for this species.

What can the species be used for?

No recorded uses.



Spondias axillaris Roxb. (Anarcardiaceae) — Ma Kak

Synonym: *Choerospondias axillaris* (Roxb.) Burtt & Hill

A medium-sized, deciduous tree, growing up to 25 m tall (DBH to 50 cm).

Where does it grow?

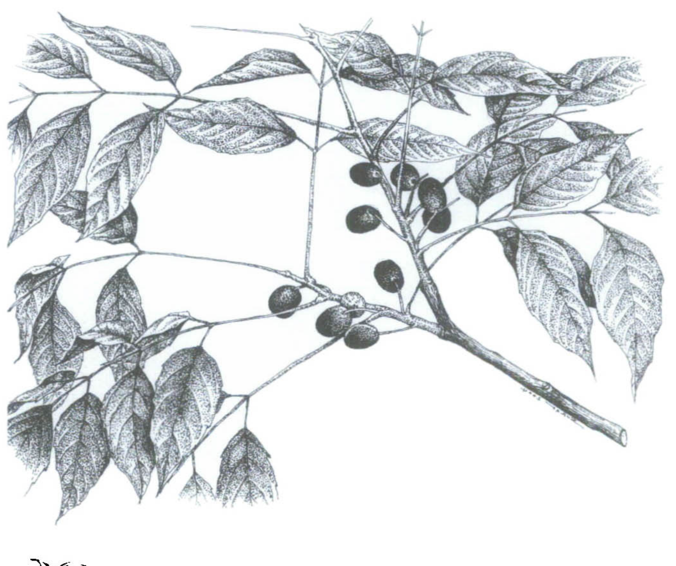
From NE. India and China through Indo-china to S. Japan. In N. Thailand, it is common in EGF, EGF-PINE and MXF, at elevations of 700 to 1600 m.

What are its distinguishing characteristics?

Bark: grey-brown, thin, vertically cracked. ***Leaves:*** spirally arranged, compound, once pinnate, 25-40 cm long; leaflet blades opposite or sub-opposite, ovate to ovate-lanceolate, 4-12 x 2-4.5 cm; apex acuminate. ***Flowers:*** male inflorescences 4-10 cm long; male corollas dark reddish purple, 0.4-0.5 cm; females solitary in upper leaf axils; January to March. ***Fruits:*** drupes, oval-shaped, with yellow leathery exo-carp when ripe, 2.5-3 x 2 cm across, each containing a single pyrene with 5 locules; June to August; animal-dispersed.

Why is it a framework species?

S. axillaris is an excellent framework species. Planted saplings achieve very high survival and growth rates (>70% survival; averaging >2.5 m tall by end of 2nd rainy season). The trunks tend to fork low down, resulting in multiple crowns, which shade out weeds very effectively. Flowering and fruiting occur from the 4th year after planting. The trees support nesting birds from the 5th year after planting. The fruits are eaten by deer, wild pigs and bears. This species is very resilient after fire (100% survival of trees burnt 33 months after planting; RCD >35 mm).



How are saplings grown?

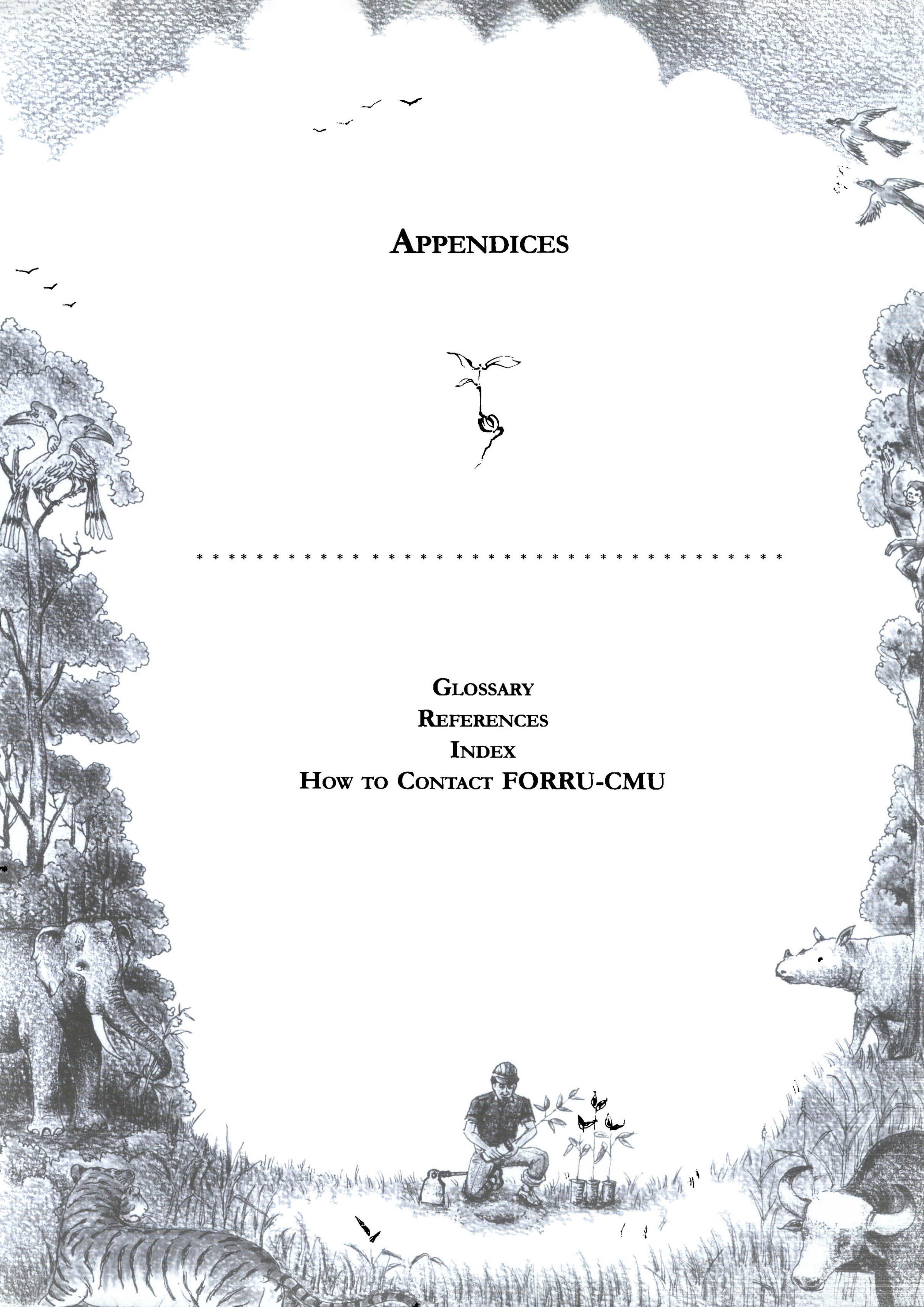
Collect ripe fruits from the ground in July or August. Soak them in water for 1 week to soften flesh, then remove the flesh by rubbing fruits in a coarse sieve under running water. Drop pyrenes into water and discard those that float. Sun-dry those that sink for 2-3 days. Store them in open containers until October, then sow them at low density in trays in sunlight. Do not attempt to remove seeds from the pyrenes. Up to 5 seeds may germinate from each pyrene. Mean GP 42%; MLD 90 days. Germination is asynchronous, requiring intermitent pricking-out. Saplings grow tall enough (*i.e.* >30 cm) by the 1st planting season after seed collection (TNT 8 months, excluding seed storage).

How should saplings be planted and cared for?

S. axillaris saplings respond well to card-board mulch, applied for 2 growing seasons. The species is also suitable for direct seedling.

What can the species be used for?

Its wood is used for interior finish, carvings, packing crates, plywood, firewood and pulp for paper. Leaves can be used as cattle fodder.



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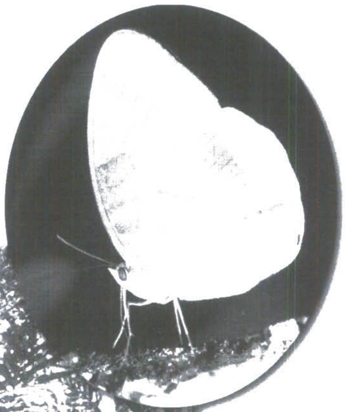
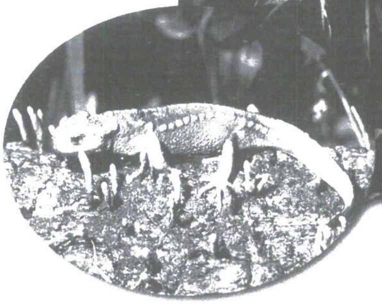
Biodiversity Conservation is the Ultimate Aim of Forest Restoration

Evergreen forest at 1,300 m elevation in Doi Suthep-Pui National Park, part of northern Thailand's natural heritage

Indian Pied Hornbill - an important disperser of large tree seeds.



One of Thailand's many butterfly species - insects are by far the largest component of biodiversity.



Crocodile Salamander - one of many endangered species that benefit from forest restoration.

Sambar Deer - many large mammals are becoming rare due to hunting.

Unlike other forms of reforestation, forest restoration focuses on conserving as many of the species that formerly lived in the original forest ecosystem as possible. Northern Thailand's forests support at least 3,450 vascular plant species (including 1,116 trees) (CMU Herbarium Database); 383 bird species (Round, 1988) and 150 mammal species (Lekagul and McNeely, 1988), as well as many endangered species such as the Crocodile Salmander (bottom left). The number of insect species is so high (probably tens of thousands), it has yet to be properly counted, but it includes at least 500 butterflies. Forest destruction is the main threat to these species; forest restoration could be their salvation.

Glossary

Accelerated (assisted) natural regeneration ANR: management actions to enhance the natural processes of forest succession.

Achene: a small, dry, indehiscent, one-seeded fruit with thin pericarp.

Acorn: fruit of oaks; a nut with a cupule.

Acuminate: apex with concave sides, tapering to an extended point

Alternate: placed singly along a stem or axis (not opposite or whorled).

Angiosperms: one of the main divisions of flowering plants, containing plants that have ovules enclosed in an ovary.

ANOVA: analysis of variance. A statistical test to determine significant differences among experimental treatments or species *etc.*

Anther: the part of the stamen which produces pollen.

Apex: the tip, *e.g.* of a leaf.

Aril: a fleshy, usually brightly coloured extra cover of a seed (arising from the hilum), which is free from the seed.

Axillary: postioned in the angle formed by the upper side of a leaf and the stem.

Axis: the central line of symmetry of a plant or plant part.

Bark: tough outer covering of woody stems or roots.

Berry: a simple fruit, developing from a single pistil, usually small, with several seeds within a juicy mesocarp.

Biodiversity: the variety of life encompassing genes, species and ecosystems.

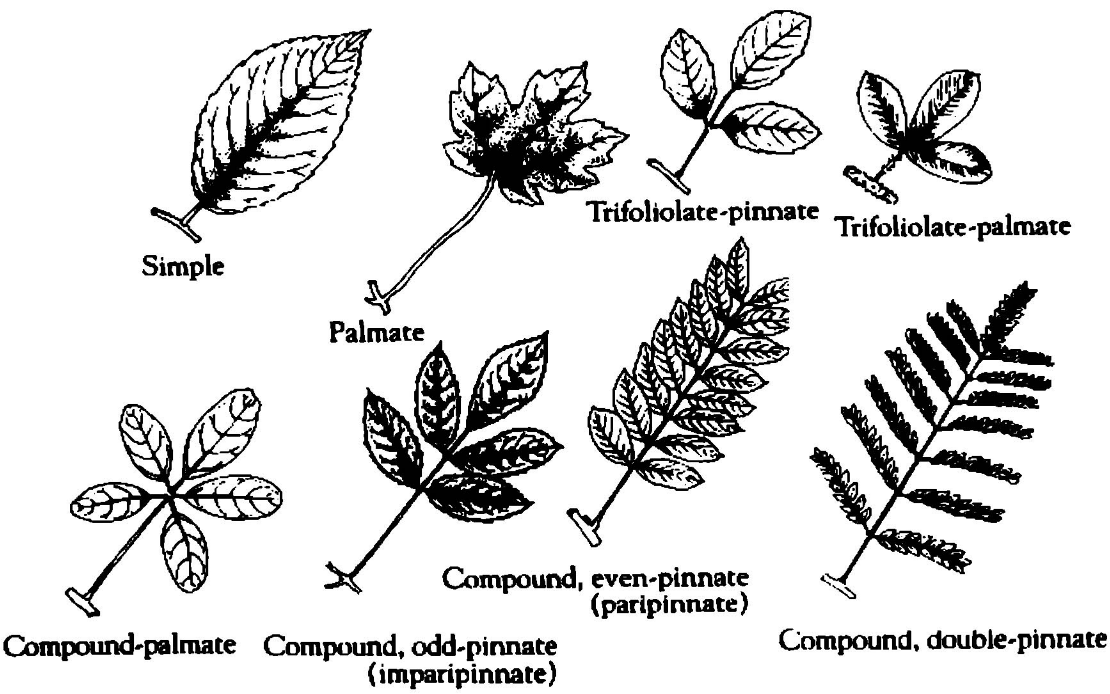
Bimorphic: having two forms.

Bivalved: with two valves.

Blade: the expanded part of a leaf or petal.

Bole: stem or trunk of a tree.

Leaf Types



Bud: an undeveloped (or dormant) leaf, flower or shoot protected by scales (bracts).

Buttress: a vertical projection at the base of a tree trunk, originating from a lateral root.

Calyx: united sepals of a flower.

Capsule: a one- to many-seeded, dry fruit, which splits into valves when ripe.

Carpel: the ovary, stigma and style.

Climax forest: undisturbed, stable, forest at maximum development in terms of structure and species composition, determined by soil and climatic conditions.

Community forest: a forest that is managed collectively by local people.

Compound: with more than one similar parts in one organ *e.g.* leaves.

Coppicing: with many shoots growing out from tree stumps.

Corolla: united petals of a flower.

Cotyledon: seed leaf; part of the embryo of a seed plant.

Cupule: enclosing structure, originating from the base of nuts formed of dry, enlarged bracts *e.g.* around nuts of *Quercus* and *Lithocarpus* species.

Cyme (adjective **cymose**): a type of branching inflorescence, in which the central and terminal flower opens first.

Damping-off: various fungal diseases, which attack young seedlings, causing stem collapse and death.

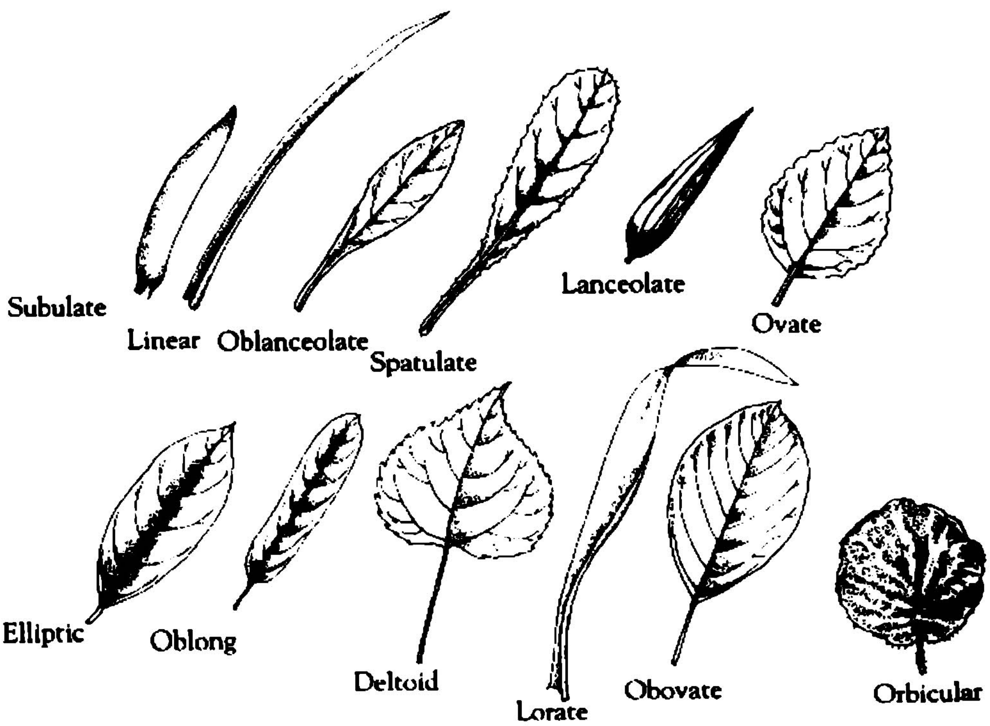
Deciduous: shedding leaves annually or periodically; not evergreen.

Dehiscent: splitting open (see capsule)

Dicotyledon: one of the two great divisions of Angiosperms, having embryos with two seed leaves or cotyledons.

Dormancy: the period between seed dispersal and germination, during which germination is delayed, despite suitable conditions prevailing.

Leaf Form



Leaf Shapes - Quick Definitions

Length/width	Widest at the:		
	Apex	Middle	Base
+/- 1		Orbicular	
1-2	Obovate	Elliptic	Ovate
2-3	Obovate-oblong	Oblong	Ovate-oblong
3-5	Obovate-lanceolate	Lanceolate	Ovate-lanceolate
5-10		Linear-lanceolate	
10+		Linear-subulate	

J. F. Maxwell

DNP: The Thailand Government's Department of National Parks, Wildlife and Plant Conservation.

Drupe: a fleshy fruit, in which one or more seeds are enclosed within a stony inner layer (endocarp).

Ecology: the scientific study of the factors determining the distribution and abundance of plants and animals.

Ecosystem: any area or space, within which living organisms and the non-living environment interact to bring about an exchange of materials between the living and non-living parts of the system.

Elliptic: refers to a shape (usually a leaf) that is widest in the middle and tapers towards both ends.

Embryo: rudimentary shoot and root within the seed.

Emergent: arising above the soil, becoming visible; or describing a tree with a crown rising above the main forest canopy.

EMR: East Malling Research, U.K., FORRU's Darwin Project Partner (formerly HRI).

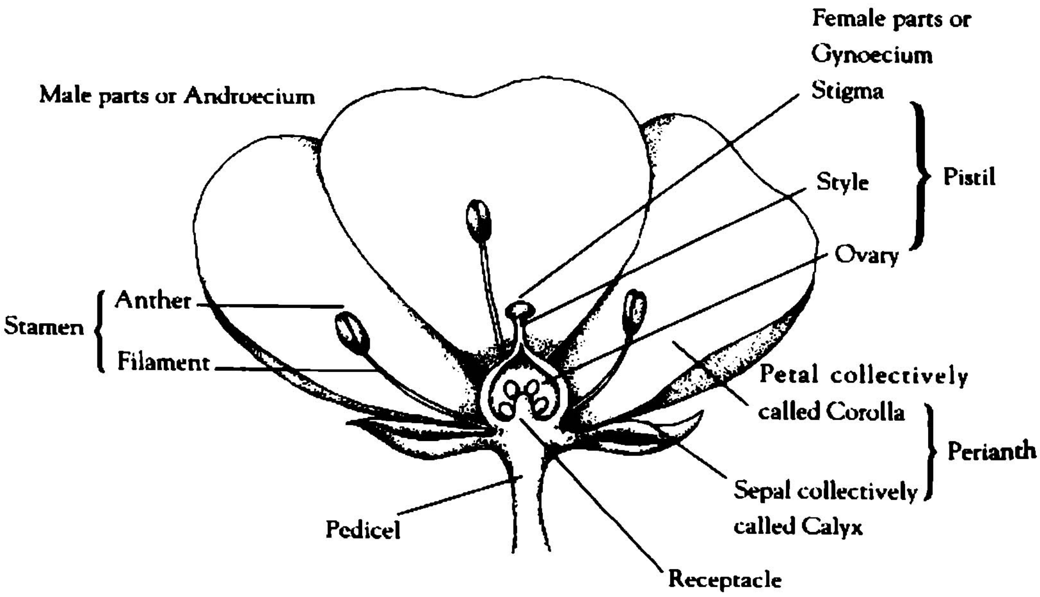
Endemic: indigenous to and confined to a particular area.

Endocarp: the inner layer of the pericarp or fruit wall.

Endosperm: tissue formed from the embryo sac, which stores nutritive material in seeds.

Entire: of leaf margins - not toothed or divided in any way.

Flower Parts



Epicotyl: the part of a seedling above the cotyledons that gives rise to the stem and leaves.

Epiphyte: (adjective **epiphytic**): a plant growing upon, but not nourished by, another plant.

Epilithic: growing on rocks.

Evergreen: a plant that retains green foliage throughout the year.

Exocarp: the outer layer of the pericarp or fruit wall.

Exotic: of species - introduced, not native.

Extirpation: the disappearance of a species from a local area.

Extinction: the complete loss of a species globally; when no more individuals of a species exist.

Fire break: a strip of land cleared of vegetation, to prevent the spread of wild fires.

Fissure: longitudinal splits or cracks.

Flower: the structure for sexual reproduction in the Angiosperms, usually consisting of male organs (comprising the stamens) and female organs (comprising the pistils).

Forest landscape restoration (FLR): integrated management of all landscape functions in deforested or degraded areas to regain ecological integrity and enhance human well-being; usually including some forest restoration.

Forest restoration: any activity aimed at re-establishing the forest ecosystem originally present on a deforested site before deforestation occurred; one particular kind of reforestation.

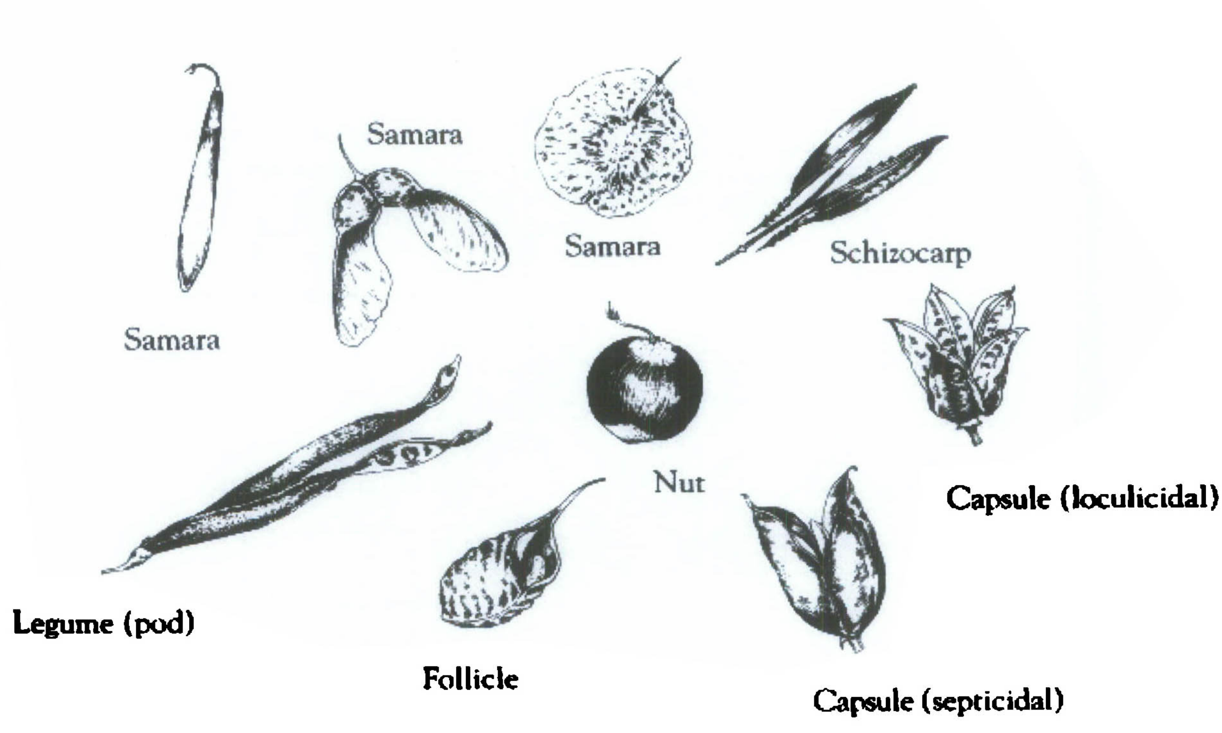
Framework species method: planting indigenous forest tree species, which can rapidly re-establish canopy cover and attract seed-dispersing wildlife, to accelerate forest regeneration and biodiversity recovery.

Fruit: the ripened ovary bearing the seeds.

Funicle: the connection between an ovule and its placenta.

GBH = girth at breast height: the circumference of a tree trunk measured 1.3 m above the ground.

Dry Fruit Types



Genus: a group of closely related species.

Glabrous: not hairy.

Gland: a secreting organ, often dot or wart-like, either on the surface of or embedded in tissue.

Glaucous: with a waxy, greyish-blue bloom.

Globose: spherical, round.

Glomerule (adjective **glomerulate**): a dense cluster of short-stalked flowers.

GP = germination percent: the number of seeds which germinate divided by the number sown, multiplied by 100.

ha (Hectare): an area of land equal to 10,000 square metres.

Habit: the characteristic growth form of a plant species *e.g.* as a tree, shrub, herb *etc.*

Hardening-off: the process of gradually acclimatizing seedlings in the nursery to the conditions they will be subject to after planting out.

Herbarium: a collect of dried plant specimens for scientific study.

Hemiparasitic: partially parasitic; plants that absorb nutriment from other plants, but retain green tissues that carry out photosynthesis.

Hilum: a scar left on a seed where it was previously attached to the funicle.

HRI: Horticulture Research International; the former name of EMR.

Hypocotyl: the axis of an embryo below the cotyledons, which, on germination, produces the radicle.

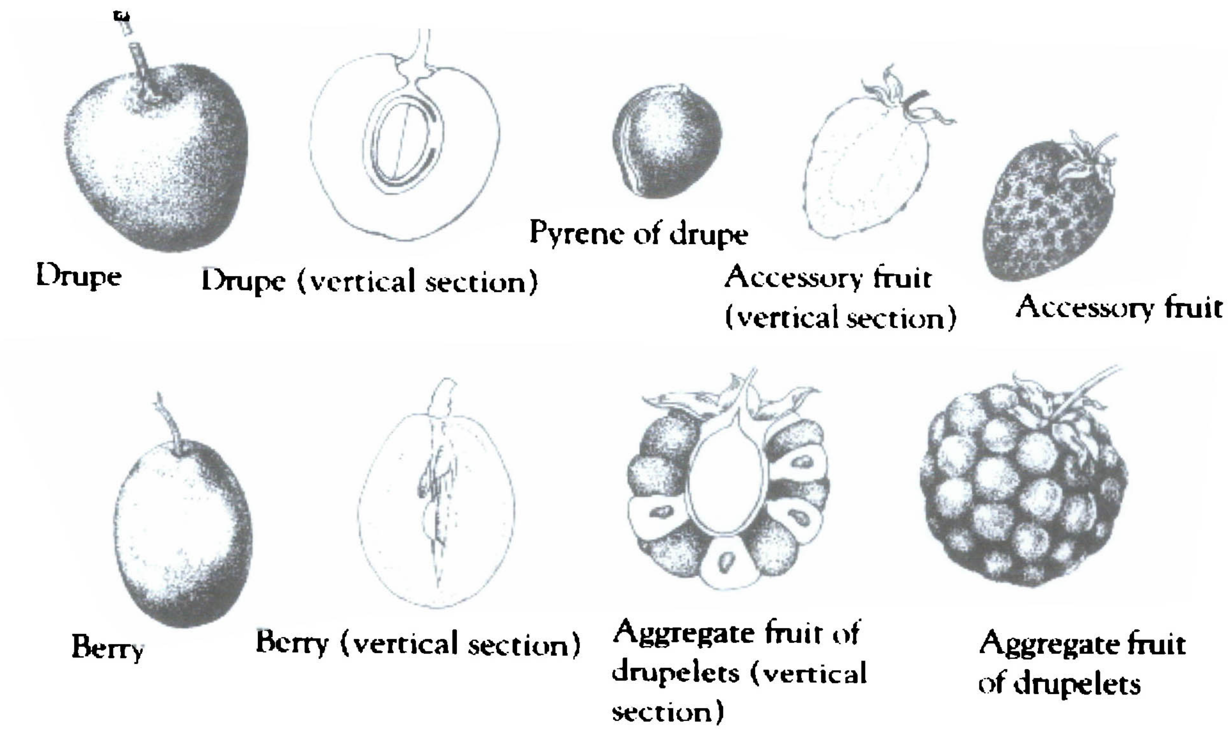
Imparipinnate: odd-pinnate; with an unequal number of leaflets.

Indehiscent: not splitting open (*e.g.* of fruits).

Indigenous: native to an area, not introduced: the opposite of exotic.

Inflorescence: the arrangement of flowers along a floral axis; a cluster of flowers.

Fleshy Fruit Types



Infructescence: a cluster of fruits derived from an inflorescence.

Internode: a length of stem between two adjacent nodes.

Lanceolate: shaped like the head of a spear or lance, with the widest part at the middle.

Lateral: on or at the side.

Leaf-exchanging: young leaves flushing more or less at the same time as senescent leaves are shed.

Leaflet: lateral axis of a compound leaf.

Legume: a dry fruit of one carpel, often splitting along one or both sides.

Lenticel: a pore in a stem, often surrounded by a raised corky margin, for gaseous exchange.

Lenticellate: bearing lenticels.

Lignified: becoming woody, due to thickening of cell walls by deposition of lignin.

Lobe: any curved or rounded part or segment of any organ; specifically a part of a petal; calyx or leaf blade.

Locule: ovary chamber, containing the ovules or anther chamber containing the pollen.

Longitudinal: along the vertical axis of an organ.

Margin: the outer edge of *e.g.* a leaf blade or petal.

Masting: mass fruiting erratically, once every several years, a common fruiting pattern amongst species of the family Fagaceae.

Mesocarp: the middle layer of the fruit wall or pericarp.

Midrib/mid-vein: the primary vein of *e.g.* of a leaf blade.

MLD median length of dormancy: the number of days between sowing seeds and germination of half the seeds that eventually germinate.

Monocarpic: flowering and fruting once only, followed by death.

Monocotyledon: one of the two great divisions of angiosperms; embryos with one cotyledon.

Monopodial: with a simple main stem, growing from the apex and having lateral branches.

Mychorrhiza: a mutualistic association between vascular plant roots and fungi.

Nectar: a sugary solution, secreted by many flowers, which attracts animal pollinators.

Node: the point on an axis where leaves, flowers *etc.* are borne.

Nut: a simple, dry, one-seeded fruit with a hard pericarp.

Oblong: longer than broad, widest in the middle.

Obovate: the inverse of ovate, with the broadest part towards the top.

Obovoid: of *e.g.* a fruit, egg-shaped, with the base as the narrower end.

Opposite: leaf arrangement, in which the leaves arise opposite to each other at a node.

Ovary: the part of the flower containing the ovules and later the seeds, usually with one or more styles and stigmas.

Ovate: with an oval outline, broader towards the base than the apex and round-ended.

Ovoid: ovate in 3 dimensions, egg-shaped, attached at the broad end.

Panicle: a type of inflorescence with the main axis divided into branches, each bearing several flowers.

Paniculate: arranged in a panicle.

Paripinnate: a compound leaf divided into pairs of leaflets, with no terminal leaflet, *i.e.* an even number.

Pectinate: having tooth-like projections, like those of a comb.

Pedicel: the stalk of a single flower.

Peduncle: the stalk of an inflorescence.

Peltate: (of leaves) circular with petiole attached to the centre of the under-surface.

Perianth: collective term for the outer, non-reproductive parts of flowers (often differentiated into corolla and calyx).

Pericarp: the wall of a fruit, developed from the ovary wall, usually with three layers: exocarp, mesocarp and endocarp.

Petal: free parts of the second whorl of a flower.

Petiolate: having a petiole.

Petiole: stalk of a leaf.

Petiolule: stalk of a leaflet.

Phenology: the study of seasonal cycles of biological phenomena *e.g.* the periodic flowering and fruiting of trees.

Pinnate: compound leaf with leaflets along each side of a primary axis.

Pistil: the female parts of a flower, comprised of ovary; style and stigma.

Pod: the fruit of legumes, often splitting open along one valve.

Pollen: minute grains, containing the male reproductive cells of flowering plants.

Pricking-out: lifting seedlings from germination trays and potting them into containers.

Primary forest: undisturbed forest at maximum development in terms of structure and species composition (=climax forest).

Pyrene: a structure including the hard endocarp of a drupe and the seed(s) enclosed within.

Raceme (adjective **racemose**): an inflorescence with stalked flowers that are borne along an unbranched axis.

Rai: the standard unit of land area measurement in Thailand; equal to 1,600 square metres.

Receptacle: the enlarged extremity of an axis, bearing the flower. The walls of figs are receptacles.

Reforestation: planting trees to re-establish tree cover of any kind; includes plantation forestry, agroforestry, community forestry and forest restoration.

RCD = root collar diameter: the diameter of the root collar, usually measured with callipers, using a Vernier scale. The root collar is the point at which the above-ground parts of a plant meet the tap-root.

RFD: the Royal Thai Forest Department.

RGR = relative growth rate: Incremental growth, proportional to the average size of the plant during the measurement period. Allows growth to be compared amongst plants of different sizes.

Root trainers: containers with vertical ridges to direct root growth downwards and prevent root spiralling.

Sapling: a young tree, larger than a seedling, but not yet mature,

Saponins: a group of toxic soapy chemicals (glucosides).

Saprophytic: obtaining carbon and energy from the decomposition of organic matter.

Sarcotesta: a fleshy outer seed coat.

Scarious: membranous, dry parts that are not green.

Seed: the unit of sexual reproduction developed from a fertilised ovule, consisting of an embryo enclosed within a testa, potentially capable of germination.

Seed coat: outer, protective covering of seed (testa).

Seed predator: any animal, which destroys seeds without successfully dispersing them.

Seedling: a very young plant, just after germination, which is still dependent on food reserves from the seed.

Sepal: free part of the outer envelope of a flower.

Septum (plural **septa**): wall between locules of an ovary.

Septicidal: dehiscence longitudinally through septa so that carpels are separated.

Serrate: toothed, like a saw, with teeth pointing forwards.

Sheath: the base of a leaf or leaf stalk that embraces the stem.

Simple: a leaf with one blade.

Sinuous/sinuate: (of margins) wavy.

Spicate: spike-like.

Spike: a simple unbranched inflorescence, bearing stalk-less flowers.

Spiral: with parts arranged in spirals.

Stalk: the 'stem' of any organ *e.g.* petiole, peduncle; pedicel; filament.

Stamen: the male reproductive organ of a flower, composed of a filament and anther, the latter producing pollen.

Stem: the main axis of a plant; leaf bearing and flower bearing, as distinguished from the root-bearing axis.

Stigma: the receptive part of the female reproductive organs, at the top of the ovary, on which pollen grains germinate.

Stipule: a leaf-like or scale-like outgrowth at the base of a petiole.

Striations: parallel longitudinal lines or grooves, *e.g.* on bark.

Style: the elongated apical part of a carpel or ovary, bearing the stigma at its tip.

Subglobose: nearly globose.

Subopposite: nearly opposite.

Suborbicular: nearly orbicular.

Sympodial: growth pattern, in which shoots cease to grow and one or more lateral buds, next to the apical bud, grow repeating the pattern.

Syconium: a type of fleshy multiple fruit, enclosed by a receptacle (*i.e.* a fig).

Tannins: a group of astringent chemicals in the bark and leaves of some tree species.

Tepal: a flower segment that is not clearly differentiated into a sepal or petal.

Terminal: at the tip or apex of an axis.

Testa: outer coat of a seed (developed from the integument).

Thyrse (adjective **thyrsoid**): densely branched inflorescence, broadest in the middle and in which the mode of branching is cymose.

Toothed: bearing small projections around the edge, as in the margin of some leaf blades.

TNT = total nursery time: the number of months required to grow saplings from seed sowing until optimal planting time (not including seed storage time).

Treelet: a small tree <5 m tall at maturity.

Trifoliate: a compound leaf having three leaflets.

Tubercle: small rounded protuberance.

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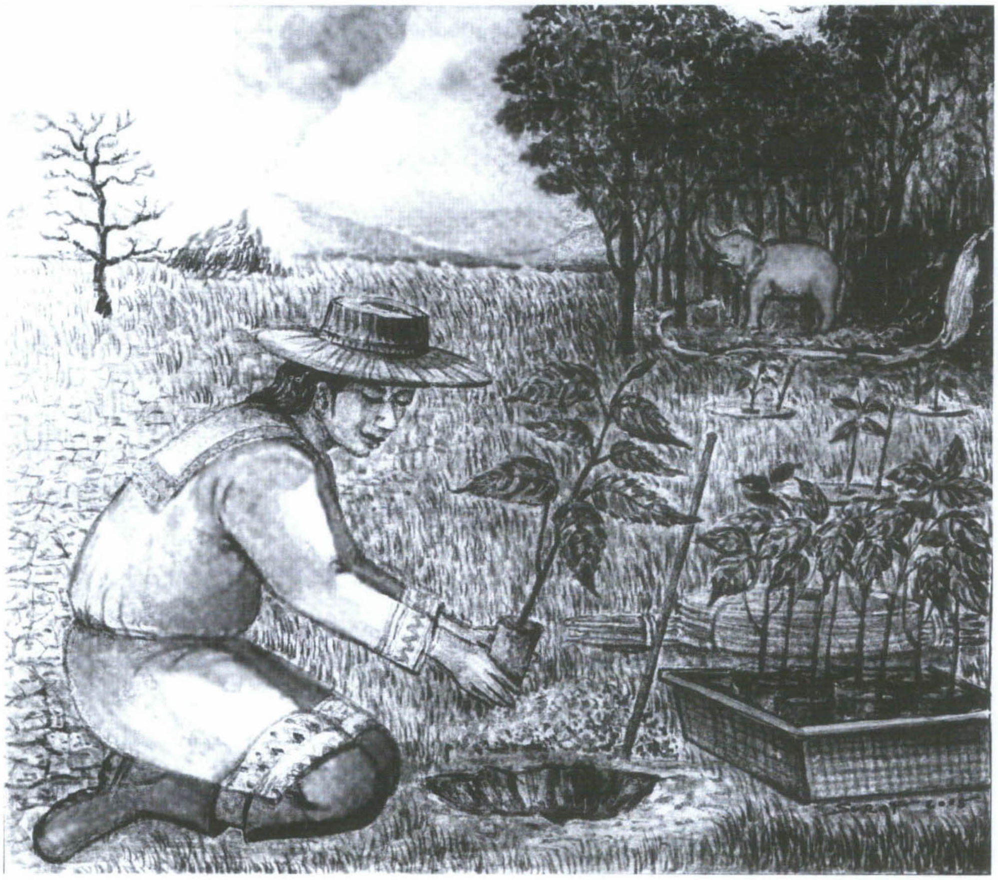


Above - Forest restoration is no longer a fantasy but a realistically achievable goal.

Back Cover - Children of Ban Mae Sa Mai proudly hold saplings of framework tree species, which they have helped to grow in their community tree nursery.

FORRU-CMU - Milestones

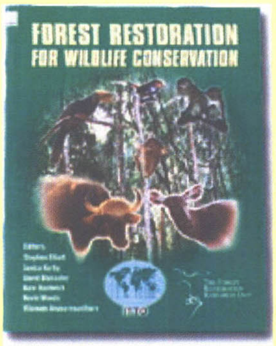
1994 - *FORRU-CMU opens its research nursery in Doi Suthep-Pui National Park (above), funded by Riche Monde Bangkok Ltd. Research on growing native forest tree species begins.*

1997 - *FORRU staff learns about the framework species method from Mr. Nigel Tucker in Australia (above).*

1996 *FORRU-CMU begins collaboration with Ban Mae Sa Mai - a community nursery is built (left) and experimental plots are planted (right).*

1998-2005 - *Planted plots become forest (7 year-old plot, above). 61 recruit tree species establish naturally beneath 30 planted framework species. Bird species increase from 30 to 81.*

2000 - *FORRU-CMU hosts regional meet: "Forest Restoration for Wildlife Conservation" (below), sponsored by ITTO, which sets an agenda for forest restoration research in Southeast Asia (right).*



1998 & 2000 - *FORRU publishes "Forests for the Future" and "Tree Seeds and Seedlings for Restoring Forests" (left) based on its initial research results.*

2005 - *FORRU featured in BBC documentary (above).*

2000 - *FORRU-CMU wins award for tree care from RFD (above). A year later, the unit is acknowledged as among the country's top 15 science projects by the Thailand Research Fund.*

2004 - *The British Minister of the Environment, the Rt. Hon. Elliot Morley MP, visits FORRU-CMU and Ban Mae Sa Mai (above).*

"Tropical forests, once destroyed, are lost forever" NOT TRUE.

It *is* possible to transform largely deforested landscapes into lush tropical forests, supporting rich biodiversity, in just a few years. Based on the work of Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) since 1994, "How to Plant a Forest" shows how the framework species method of forest restoration has been successfully adapted to re-establish natural forest ecosystems in northern Thailand. It presents background information that enables readers to understand the natural mechanisms of forest regeneration, as well as practical techniques to harness and accelerate them. Richly illustrated with easy-to-follow diagrams, this book provides scientifically tested advice on how to select appropriate tree species; how to grow them in nurseries and how to plant and take care of them in deforested areas. In addition, the logistics of implementing forest restoration projects are explained and, most importantly, how to motivate and involve local people. This book is not just about northern Thailand. The concepts and techniques described in it could be applied equally well to a wide range of different forest types in other areas, so anyone interested in restoring forest ecosystems for wildlife conservation and environmental protection will find it useful.

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Wildlife Landscapes