



**Choice of quality planting stock of teak
the question of a "genetic business plan"**

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Published in:
Innovations in the management of planted teak forests

Publication date:
2011

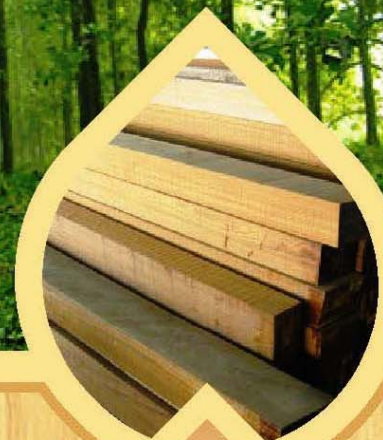
Document version
Early version, also known as pre-print

Citation for published version (APA):
Kjær, E. D., Graudal, L. O. V., Ditlevsen, B., & Hansen, J. K. (2011). Choice of quality planting stock of teak: the question of a "genetic business plan". In K. Jayaraman, & K. V. Bhat (Eds.), *Innovations in the management of planted teak forests: Proceedings of the International Training Programme, Kerala Forest Research Institute, Peechi, India, 2011* TEAKNET/KFRI.

Innovations in the Management of Planted Teak Forests

Peechi, Kerala, India

31 August - 3 September 2011



Proceedings of the International Training Programme

Innovations in the Management of Planted Teak Forests

Kerala Forest Research Institute, Peechi, India

31 August- 3 September 2011

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TEAKNET (International Teak R & D Network)



Kerala Forest Research Institute



Food and Agriculture Organisation (FAO) of the United Nations



Kerala State Council for Science, Technology and Environment

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Executive summary

An international training programme on teak titled 'Innovations in the management of planted teak forests' was conducted at Peechi, India during 31 August- 3 September 2011 by TEAKNET in collaboration with Kerala Forest Research Institute under the auspices of the FAO of the United Nations, RAP, Bangkok. The programme was supported also by the Kerala State Council for Science, Technology and Environment, Government of Kerala.

The training programme was meant to bring stakeholders of the teak sector face to face with top experts in various aspects of teak cultivation and management. The programme was attended by 37 participants from 8 different countries. Other than regular lecture sessions, there were sessions on group interaction and feedback making the programme as good as a training workshop. The participants, in general, found the programme to be very useful and informative. Some of the major issues regarding forest policy, ecological services offered by planted teak forests, plantation management and utilization of wood including marketing were covered. The deliberations during the workshop could bring to surface many practical aspects of teak cultivation and marketing. The programme worked out to be another important milestone in the promotional efforts TEAKNET is making with the ample support of FAO of the United Nations which is the founding agency of the network.

Acknowledgements

TEAKNET along with KFRI wishes to place on record the profound support that is being received from FAO of the United Nations-RAPA, especially from Dr. S. Appanah, National Forest Programme Advisor, Thailand in holding many conferences and workshops in the past and the current one on teak.

Thanks are also due to the Kerala State Council for Science, Technology and Environment for the financial and technical support extended. The contributions made by Dr. C.T.S. Nair, former Executive Vice President and Dr. N.P. Kurian who was in charge of the Council when the training programme was held, are gratefully acknowledged.

It was only with the wholehearted support of the many Scientific and Technical Staff of Kerala Forest Research Institute that this programme could be successfully executed. In this respect, the contributions made by Dr. K.V. Sankaran, Director, KFRI are gratefully acknowledged.

**Report on the International Training Programme on teak
'Innovations in the Management of Planted Teak Forests'
31 August - 3 September 2011, Kerala Forest Research Institute, Peechi,
Kerala, India**

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Background

Teak (*Tectona grandis*) is being grown in plantations in around 70 countries across the globe although its natural occurrence is limited to India, Laos, Myanmar and Thailand. Of the estimated 142 million hectares of global plantations in 2005, about 5.82 million hectares (4%) were teak, the major producers being India, Indonesia, Myanmar and Thailand in the Asia Pacific region. Of late, there has also been much interest in planting teak in South American Countries. With such a heightened level of interest in teak, FAO has been collaborating with several countries to undertake studies, conduct workshops and promote the exchange of genetic material and information both on growing and marketing of teak and its products. TEAKNET, an international network on teak established in 1995 with the support of FAO offered a convenient platform for promotional activities on teak by the FAO. The network headquarters is currently located in KFRI, Thrissur, India. The network, with its wide pool of members, is promoting teak-related studies, workshops and meetings actively.

One major objective of TEAKNET is to generate knowledge and disseminate information on all teak-related issues. Providing a training that combines topics on innovative teak cultivation practices with recent developments that influence the teak business, such as climate change and participatory tree farm initiatives would contribute to the renewal and strengthening of the teak wood sector and rural development. This programme was thus aimed to bring the actual stakeholders of the teak sector face to face with topmost experts for exchanging information on the innovations that have been happening in the industry globally in all its dimensions.

Objectives

The major objective of the programme was to familiarize the various stakeholders with the innovations in the technology of growing and utilizing teak. The programme also would bring to discussion issues like supportive policies, legal frameworks, climate change, ecological services and on the whole teak farms as an instrument for economic growth in rural Asia.

Organizers and sponsors

The workshop was organised by TEAKNET in collaboration with the Kerala Forest Research Institute. TEAKNET is an international network of institutions and individuals interested in teak. TEAKNET addresses the interests of all categories of stakeholders related to teak, whether they are growers, traders, researchers or other groups with a

profound interest or concerned with teak. TEAKNET was established in 1995 and its headquarters was recently shifted from Myanmar to India. Financial support for the workshop was provided by FAO of the United Nations and also the Kerala State Council for Science, technology and Environment, Government of Kerala.

Participants and speakers

The programme was held at the Peechi campus of KFRI and was attended by a total of 37 participants from 8 different countries including India. The participants represented a cross section of the major sets of stakeholders like growers and researchers. The list of participants is furnished in the appendix of this report. Several eminent scientists and experts in various fields of tropical timber development programmes were invited from around the world to deliver the lectures.

Inaugural function

The inaugural function of the workshop was held in the forenoon of 31 Aug. 2011. Dr. N.P. Kurian, Executive Vice President in charge of Kerala State Council for Science and Technology welcomed the dignitaries and the participants. Mr. M.P. Vincent, MLA, Kerala Legislative Assembly presided over the function. The workshop was inaugurated by Dr. Markku Kanninen, Director of Viikki Tropical Resources Institute, Finland and Professor, University of Helsinki, Finland. Dr. Markku Kanninen delivered the inaugural address.

Dr. K. Jayaraman, TEAKNET Coordinator explained the objectives of the workshop. Dr. S. Appanah, National Forest Programme Adviser, FAO, Bangkok spoke on the occasion indicating the role of FAO in promoting forestry and in particular teak in the region. Mr. P.V. Pathrose, President, Pananchery Grama Panchayath offered felicitations to the workshop. Dr. K. V. Sankaran, Director, KFRI proposed vote of thanks.

Technical Sessions

The technical sessions that followed centred, in general, on the following topics:

- Supportive policies and legal frameworks for growing teak
- Choice of quality planting material for teak
- Mass production of quality planting stock of teak
- Soil management in teak plantations
- Forest-level management planning
- Health and sustainable management of teak stands
- Innovative approaches in utilization of teak wood
- Teak plantations for climate change mitigation and ecological services
- Teak farms – a strategy for growth and job creation in rural Asia

At the start of each session, the chairperson and the rapporteur for the session were introduced. The chairpersons briefly indicated the overall expectations from each session before calling on the speakers. The details of the sessions are the following.

Wednesday, 31 August 2011

Day 1

Technical Session- I: Policy and legal framework

Venue: Tectona Hall, KFRI

Chair

Dr. Markku Kanninen

Professor of Tropical Silviculture &
Director
Viikki Tropical Resources Institute (VITRI)
University of Helsinki, Finland/CIFOR
Indonesia

Rapporteur

Dr. V. Anitha

Scientist- EI
Forestry and Human Dimension Division
Kerala Forest Research Institute
India

12.00-13.00 **Supportive policies and legal frameworks for growing teak**

Dr. S. Appanah
National Forest Programme Adviser
FAO Regional Office for Asia and the Pacific, Bangkok

13.00-14.00 **Lunch Break**

Technical Session- II: Tree improvement and mass propagation

Venue: Tectona Hall, KFRI

Chair

Dr. K. Palanisamy

Scientist -F & Head
Forest Genetic Resources and
Management Division
Institute of Forest Genetics and Tree
Breeding (ICFRE),
India

Rapporteur

Dr. T.B. Suma

Scientist- B
Forest Genetics & Biotechnology
Division
Kerala Forest Research Institute
India

14.00-15.00 **Choice of quality planting material for teak**

Dr. Jon Kehlet Hansen
Senior Scientist (Forest Genetics), Forest & Landscape Denmark
Faculty of Life Sciences, University of Copenhagen, Denmark

15.00-15.30 **Tea Break**

15.30-16.30 **Mass production of planting stock of teak**

Dr. Shuchishweta V. Kendurkar
Principal Scientist
National Chemical Laboratory
Pune, India

16.30-18.30 **Break**
18.30-20.30 **Cultural Programme at Auditorium, KFRI**

Thursday, 1 September 2011

Day 2

Technical Session- III: Plantation management

Venue: Tectona Hall, KFRI

Chair

Dr. Manoranjan Bhanja
Additional PCCF,
Andhra Pradesh Forest Department,
India

Rapporteur

Dr. S. Sandeep
Scientist- B
Sustainable Forest Management Division
Kerala Forest Research Institute
India

- 09.30-10.30 **Soil management in teak plantations**
Dr. B. Mohan Kumar
Associate Dean, College of Forestry
Kerala Agricultural University
Thrissur, India
- 10.30-11.30 **Forest-level management planning**
Dr. Juha Lappi
Senior Research Methods Specialist
Finnish Forest Research Institute, Suonenjoki
Finland
- 11.30-12.00 **Tea Break**
- 12.00-13.00 **Health and sustainable management of teak stands**
Dr. V.V. Sudheendrakumar
Scientist-F & Head, Department of Entomology, Forest Health Division
Kerala Forest Research Institute
India
- 13.00-14.00 **Lunch Break**

Technical Session- IV: Wood utilization

Venue: Tectona Hall, KFRI

Chair

Dr. K. M. A. Bandara
Research Officer (Tree Breeder)
Sri Lanka Forest Department
Badulla
Sri Lanka

Rapporteur

Dr. E. V. Anoop
Associate Professor and Head
Department of Wood Science
College of Forestry
Kerala Agriculture University
India

14.00-15.00 **Innovative approaches in utilization of teak wood**
Dr. R.V. Rao (Retd.)
Institute of Wood Science & Technology
Bangalore, India

15.00-15.30 **Tea Break**

Group Interaction: Problems and prospects of teak growing and trade

Chair

Dr. S. Appanah
National Forest Programme Adviser
FAO Regional Office for Asia and the
Pacific, Bangkok
Thailand

Rapporteur

Dr. R. C. Pandalai
Scientist- F
Programme Coordinator
Extension and Training Division
Kerala Forest Research Institute
India

15.30-16.30 Group interaction/ Experience sharing

Friday, 2 September 2011

Day 3

Technical Session- V: Climate change and social dimension

Venue: Tectona Hall, KFRI

Chair

Dr. Jose Kallarackal
CSIR Emeritus Scientist
Kerala Forest Research Institute
India

Rapporteur

Dr. M. Amruth
Scientist- B
Forestry and Human Dimensions Division
Kerala Forest Research Institute
India

09.30-10.30 **Teak plantations for climate change mitigation and ecological services**
Dr. Markku Kanninen
Professor of Tropical Silviculture & Director
Viikki Tropical Resources Institute (VITRI)
University of Helsinki
Finland/CIFOR, Indonesia

10.30-11.30 **Teak farms – a strategy for growth and job creation in rural Asia**
Mr. Dede Rohadi
Center for Research and Development on Climate Change and Forestry
Policy, Forestry Research and Development Agency
Bogor, Indonesia

11.30-12.00 Tea Break
12.00-13.00 Visit to KFRI
13.00-14.00 Lunch Break

Feedback Session

Venue: Tectona Hall, KFRI

Chair

Dr. S. Appanah
National Forest Programme Adviser
FAO Regional Office for Asia and
the Pacific, Bangkok

Rapporteur

Dr. K. Jayaraman
TEAKNET Coordinator
Kerala Forest Research Institute
India

14.00-15.00 **Response from participants**
15.00-15.30 **Tea Break**

Concluding Session

Venue: Tectona Hall, KFRI

15.30-16.30 **Concluding remarks : Dr. S. Appanah, FAO, Bangkok**
Vote of thanks : Dr. K. Jayaraman, TEAKNET Coordinator

19.00-21.00 **Farewell party at Hotel**

Saturday, 3 September 2011

Day 4

A field trip was organized to Nilambur. This included a visit to Conolly's plot, KFRI Sub centre, International Teak Museum and Bio-resources Park at Nilambur.

Lecture Notes

Supportive policies and legal frameworks for growing teak

Dr. S. Appanah

National Forest Programme Adviser
FAO Regional Office for Asia and the Pacific, Bangkok
Email: Simmathiri.appanah@fao.org

Abstract

The presentation addresses four key questions: the policies and legislation frameworks, their importance, how they are matched or otherwise with the changing societal needs and the issues that need to be addressed in this regard. An attempt is made to indicate the complexity of political will in the working of the legal framework by comparing certain policies and laws of Thailand (such as, the Forest Act 1964, 1985, the Thailand Forest Policy of 1986, logging ban of 1989, Reafforestation Act 1992) with those of Kerala State, (Kerala Promotion of Tree Growth in non-Forest Areas Act 2005) India. The deficiencies and weaknesses that are highlighted include outdated policies and legislation, lack of broad stakeholder consultation, imbalances in stakeholder power, weak strategic planning capabilities, weak implementation capacities, weak political will, absence of supporting legislation, strategies and operational plans, attitudes of individuals and institutions, overly prescriptive and bureaucratic environments, forestry and climate change. As corrective measures, the need to understand the ever changing policy landscape, ever increasing/different demands on forests, the institutional reinventions, changing roles for forestry professionals, new skills, new knowledge, new challenges and the drivers of the change exercise are also highlighted. The paper emphasizes the need to revisit the existing policy legal dictum as many of the existing policies and laws are not in tandem with the changing short-term and long-term societal needs.

Choice of quality planting stock of teak: The question of a 'genetic business plan'

Erik Dahl Kjær, Lars Graudal, Bjerne Ditlevsen and Jon Kehlet Hansen*

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University of Copenhagen, Rolighedsvej 23, DK-1958 Frederiksberg C, Denmark

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Abstract

The paper examines the potential options for procuring high quality planting stock of teak for planting programmes. A dedicated effort for procuring high quality planting stock is most likely to prove very profitable. As part of a plantation programme, it is suggested to develop a 'genetic business plan' to procure the best possible planting material and to develop a programme where new knowledge on performance of genetic material specific for the relevant planting locality is continuously captured and used to improve adaptation, production and quality. Thus the choice of good planting material is not an initial 'one time decision' - rather it should be an iterative process based on expanding knowledge base.

Keywords: Teak plantation programme, planting stock, genetic material, genetic business plan

Introduction

High quality planting material is an important component in small and large scale teak plantation programmes. In this connection, it is necessary to examine the quality of the provenance selected. The level of knowledge with regard to growth, stem form, heartwood percentage, and stem straightness of teak is often insufficient to recommend choice of a seed source for establishing plantations outside its natural range. The genotype-environment interaction makes it difficult to develop specific guidelines on choice of best planting stock. However, regional trials and testing for identifying better clones have their value in establishment of teak plantations outside its natural range.

Options: What? and how much? Can we gain from selection and breeding?

The variation between provenances can be substantially concerning adaptation, growth, stem form and wood quality and the choice of provenance for the given site can have important impact on the success of the plantation programme. However, one may also conclude that the level of knowledge at present rarely will be sufficient to recommend choice of seed source for a given site outside the natural range of teak.

Published studies indicate an important potential for gain through selection, e.g., selection for growth seems to be favourable and is genetically correlated with stem straightness. Special interest seems essential for improvement of heartwood quality and percentage that would allow harvesting at a younger rotation. The heartwood percentage is relatively easy to assess from wood cores and is highly inheritable. Knowledge on the genetic variation in wood quality traits is sparse and is also more cumbersome to measure. Little is known on the genetic inheritance of wood properties and very little is known about genotype - environment interactions and selected genotypes may therefore need to be tested at the locality in question.

Genotype by environment interaction: Can one clone fit all localities?

Field trials show difficulties of predicting how a provenance will perform based on the interaction between seed source and climate. The genotype-environment interaction need not be necessarily at the same level for individual genotypes as observed for provenances, but it is likely that the ranking in adaptation and performance between individual genotypes may differ between sites. Thus, local testing of applied planting material is, in many cases, of relevance. Genotype- environment interaction makes it difficult to develop specific guidelines on choice of best planting stock, and speaks in favour of developing local 'genetic business plans' that include simple data harvesting and adoption of management decisions according to the harvest experience. It also speaks in favour of local or regional efforts in development of superior seed sources/clone collections and coordinated testing programmes across sites in a given area.

The genetic business plan

Results from decades of field trials tend to show:

1. Differences, especially in survival and growth performance, can be very large between potential seed sources
2. The degree of provenance environmental interactions may be substantial.
3. The potential value of improving the applied planting stock may be substantial

The prediction of performance of a certain provenance or clone at a given planting site based on climatic conditions is uncertain and makes it necessary to set up local tests to find the most suitable genetic material. Results from the international field trials can be used to concentrate on a manageable number of genetic materials that could be of interest. The tests can be of two types:

1. Traditional tests coordinated by research organisations or as a cooperative effort between teak planting companies and organisations in the areas.
2. Local testing set up by teak planters by keeping precise track of applied planting stock at each planting site and including alternative seed sources in a way that will allow easy comparison and simple future data harvest.

Planting of genetic material tested and selected in other growing conditions than the planting site will involve some uncertainty, especially if plantings are based on a single – or a set of few clones - because genetic diversity will be limited in such planting stock, which increases the risk of a sudden, large scale damage from new pests and pathogens. In comparison, when planting a provenance, there is at least a chance that some trees within the provenance will survive and grow well. The use of less diverse genetic material is feasible once tested in the region, but it will still be advisable to maintain some genetic diversity in the plantations.

The business plan should not only ensure a systematic collection and use of local experience with different available seed sources, but should also include a seed source/germplasm development component. Combined small and large scale activities can lead to establishment of multiple breeding populations, which can be an easy and cheap approach to test genetic material and to secure future genetic improvement. Potentially superior clones can be identified and tested in this process.

To summarize, the choice of good planting stock for a given plantation programme is not an initial 'one time decision' - rather it should be an iterative process based on expanding knowledge base. It should therefore be based on: (1) what is generally known from international research, (2) what is known from local experience in the area including local tests (if any), (3) an overview of potential seed sources / selected clones that are available locally or internationally (relevant in terms of time frame, scale and costs), (4) experience and data generated as part of the on-going activities, (5) a pro-active approach to development of new seed source options (or clones) based on local (smart but low input) selection and/or more advanced coordinated effort, (6) continuous adoption of the genetic business plan based on new information available locally and internationally.

It is also important to consider how to handle genetic diversity both at the levels of the single programme and at regional level, and such consideration should therefore also be included at the plantation level. On the regional level, a coordinated effort will be required when it comes to actual *ex situ* genetic conservation activities on large scale. Local seed source development activities as discussed above can play an important role and add resilience to the gene pool by reducing the risk of rapid genetic erosion.

Micropropagation: An effective tool for mass production of quality planting stock of teak

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Abstract

Teak is an important timber species propagated mainly through seeds for large scale plantation programmes. The conventional methods of vegetative propagation have their own limitations in fulfilling the demand for superior propagules. Micropropagation has proven to be the method of choice for rapid multiplication of selected genotypes to generate true to type progeny leading to large scale production of superior propagules. Extensive work has been carried out for developing micropropagation technology; fine-tuning the protocol for genotypes from different regions of India; refining and up scaling for commercial feasibility. Further validation was done by demonstration of techno-commercial feasibility through field testing, wood quality assessment and molecular marker studies to confirm clonal homogeneity. Field trials have demonstrated higher growth and uniformity of tissue culture propagules, leading to higher wood volume as compared to conventional propagules. The wood density analysis of up to twelve year old tissue culture propagules is encouraging. The large scale field trials have contributed to awareness about the superiority of tissue culture propagules amongst the user community. This technology needs to be commercialized to reap the maximum socio-economic and environmental benefits.

Keywords: Teak micropropagation, planting stock, cryopreservation.

Introduction

Teak (*Tectona grandis* L. f.) is a tropical hardwood timber tree belonging to family Verbenaceae. It has been planted extensively within and outside its natural habitat due to its timber which is of high economic value. In India, teak has been classified mainly into three categories: moist, semi-moist and dry depending upon the geographical locations (Seth and Khan, 1958). The quality of teakwood with respect to colour, texture and figure differs with location. Teak exhibits a high degree of inter- and intra-population variations in growth performance, susceptibility to insects, fibre length and age at first flowering (Bedell, 1989). In India, extensive work has been carried out by the Forest Departments and Forest Development Corporations on identification of elite germplasm, establishment of germplasm banks, clonal seed orchards, etc. under teak improvement programmes (Kedharnath and Mathews, 1962; Kedharnath, 1983).

Need for tissue culture micropropagation

Natural regeneration of teak is largely by seeds. Large scale propagation of teak for several afforestation programmes is achieved mainly through seeds by planting seedling stumps (Jha and Choudhary, 1990). Several factors such as, low fruit production, emptiness of fruits and low germination percentage (Mathew and Vasudeva, 2003) are the major constraints. Also, due to outbreeding habit, the seed-raised progenies cannot be considered as clonal multiplication since they display high level of variation. Vegetative propagation by conventional methods of rooting of cuttings, grafting and budding have limited scope for large scale production due to low success rate and poor rooting ability of cuttings from older trees. Hence, tissue culture has been considered as

an important tool for mass multiplication of selected genotypes. Micropropagation is the process of mass propagation of selected clones via *in vitro* techniques. Shoot tip culture and axillary bud proliferation has been a method of choice for micropropagation of various tree species as the progenies exhibit high level of genetic integrity. It has long been realized that micropropagation can contribute to capturing existing genetic gains and production of true to type progeny rapidly in large numbers (Timmis, 1987).

Status of teak tissue culture in India

Studies on tissue culture of teak were taken up at National Chemical Laboratory (NCL), Pune, India during late seventies. Teak being a hardwood species, posed several challenges; mainly low response *in vitro* and browning of explants. The first report on mature tree tissue culture of teak came from NCL during 1980 when it was demonstrated that it is possible to produce plants from mature tree-derived explants (apical and nodal) from 80 to 100-year-old trees growing in Allapali forests, Maharashtra (Gupta *et al.*, 1980). Under a project sponsored by Maharashtra Forest Development Corporation Ltd. (MFDC), a bench scale protocol was developed for propagation of clones from Maharashtra region and tissue culture-raised plants were successfully field-tested (Mascarenhas *et al.*, 1987, 1993; Kendurkar *et al.*, 1991). However, considering the potential of micropropagation protocol for large scale propagation, extensive R & D work was carried out under the DBT funded tissue culture pilot plant project and the protocol was extended to genotypes from other regions of India. It was further refined and scaled up. A method for *ex vitro* rooting was also developed. Using this protocol, large number of plants were produced and planted at more than 72 locations all over India (Nadgauda *et al.*, 1997, 2000, 2003). Molecular marker (RAPD, RFLP and ISSR) studies confirmed clonal homogeneity of these plants (unpublished). Results from field trials indicated higher growth with respect to height and girth of tissue culture raised propagules as compared to conventional counterparts. Results on wood density analyses and projected wood volume are encouraging (Nadgauda *et al.*, 2003). Studies on cryopreservation of teak meristems using encapsulation-dehydration method were carried out (Kendurkar *et al.*, 1999). The micropropagation technology of teak developed at NCL has now been transferred to industries in India and abroad.

Simultaneously, other groups in India have also been working on improvement of micropropagation protocol for teak (Devi *et al.*, 1994; Yashoda *et al.*, 1999; Tiwari *et al.*, 2002; Fatima Shirin *et al.*, 2005).

Micropropagation of teak at NCL

Extensive studies on tissue culture of teak were carried out at NCL in the following lines:
Selection of plus trees: In collaboration with Forest Departments and Forest Development Corporations, plus trees/clones were selected on the basis of total height, diameter at breast height, clean bole height, crown height and diameter, cylindrical unfluted trunk, self pruning habit, resistance to pest and diseases, wood quality, stem taper and ability to produce regular crops of viable seeds.

Collection of material: Healthy green twigs from the apical region were collected in the fresh flush season which varied for different teak locations. They were packaged and transported to the laboratory for further processing. Methods for transport of the material to the laboratory in healthy condition were standardized.

Surface sterilization of bud wood material: The apical and axillary meristems were dissected and surface sterilized using standard protocol as reported earlier (Mascarenhas *et al.*, 1987). The meristems were then inoculated on semisolid modified Murashige and Skoog's medium (Murashige and Skoog, 1962) supplemented with kinetin, benzyl adenine, sucrose and gelling agent.

Control of phenolics: Browning of explants and medium due to phenolic exudation was a major problem for establishing the cultures. After extensive R&D on use of antioxidants, charcoal in the medium, treating with PVPP, hydrogen peroxide/ascorbic acid, etc. a simple method of serial shifting to fresh medium was adopted.

Micropropagation protocol: The micropropagation protocol included: a) initiation and establishment of shoot cultures, b) multiplication on subculture and c) rooting and hardening. The hardened plants were grown in greenhouse till the stem reached pencil thickness (2-4 mm) and were supplied as stumps to agencies for conducting field trials.

Innovation for techno-commercial feasibility

In the process of developing a technology and making micropropagation protocol commercially feasible, the basic requirement is efficiency of the protocol and applicability to the large number of selected genotypes collected from moist, semi-moist and dry regions. Extensive R & D work was carried out along the following lines:

- a) Optimization of season of collection and physiological status of the mother plant
- b) Shortening of the micropropagation protocol
- c) Optimization of physical and chemical parameters
- d) Development of *ex vitro* rooting method
- e) Improvement in hardening percentage
- f) Method for easy and successful transport to field

The major refinements in the protocol are: a simple method for control of phenolics, use of minimal media with lowest concentration of growth regulators to minimize variation, proliferation of shoots without intervening callus, improved multiplication rates and most importantly rooting *ex vitro*. Direct weaning of micro shoots under *ex vitro* condition resulted in reduction in number of steps, time and labour as rooting and hardening take place simultaneously and nursery personnel can handle these micro shoots efficiently.

These studies have resulted in significant refinements of the protocol for more than 15 genotypes collected from moist, semi-moist and dry regions of India. The protocol was scaled up and over half a million plants were produced. These plants are being field evaluated at different agroclimatic zones.

Field trials on tissue culture raised plants of teak

The tissue culture raised propagules were planted in paired plots and R&D designs at different locations with 3m x 3m spacing. The trials included clonal and provenance trials. The results indicate higher plant survival in the field. Tissue culture raised propagules exhibited higher biomass. Wood density and projected wood volume analysis point to the superiority of tissue culture propagules (Nadgauda *et al.*, 2003). Studies conducted on intercropping of wheat, leguminous crops and flowers, have

demonstrated the possibility of additional earnings to the farmers. Superior genotypes were identified for specific locations. Genetic gardens were also established.

The field trials have confirmed that teak plants require deep well drained alluvial soil for better growth performance, as the trials conducted on rocky soils, hillocks with shallow soil resulted in much branching of plants. Similarly, in the initial trials where the plants were planted individually with ample spacing, profuse branching was observed. In one of the trials conducted in Tamil Nadu, poor survival of plants was recorded due to waterlogging condition in the initial phases of the planting.

Testing for clonal homogeneity

Initially RAPD analysis of tissue culture plants with mother plants was carried out to confirm clonal homogeneity (SN Raina, personal communication). In view of the quality testing of tissue culture raised propagules using RAPD and ISSR primers, extensive studies were conducted at NCL. These studies have resulted in identifying ISSR primers which can be used to test fidelity of tissue culture raised propagules of teak.

Impact of the technology

Initially the trials were established through Forest Departments and Forest Development Corporations in the States of Maharashtra, Karnataka, Madhya Pradesh, Gujarat, Tamil Nadu and Andhra Pradesh. In order to reap the benefits of micropropagation technology and to reach to the grassroot level, demonstration plots were established at farmers' field and private owners in the later phase. The field trial design and the silvicultural practice packages were provided to agencies in order to promote proper field evaluation procedure. A proforma for collection of data from the agencies was also provided. Trials at farmers' field have created awareness among the farmers about the superiority of tissue culture raised propagules and potential of micropropagation technology to accrue economic benefits. One such example is a trial at a farmer's field near Sangli, Maharashtra where tissue culture raised propagules (age over 8 yrs) are displaying excellent growth performance (height 8-10 m, girth 60-70cm) and high degree of uniformity. Adjacent to this trial another farmer having a plot of tissue culture raised propagules purchased from a private company in South, is showing a high degree of variability, poor growth and high mortality.

Based on the feedback received from the agencies, it is clear that the following impact has been created on social, economic and environmental level:

- These trees act as good wind barriers thereby saving soil erosion and damage to nearby fields of poor farmers
- The ambient temperature has reduced by 3 to 4° C with increase in relative humidity
- The ecological balance has also improved as many animals are taking shelter and numerous species of birds are sighted

The villagers are benefited by getting employment and branches and twigs for firewood which led to decreased tree felling for fuelwood. Further, landless farmers have utilized the land between the trees for growing leguminous crops which led to nitrogen fixation and gaining nitrogen credit.

Thus it has been demonstrated that micropropagation being a labour intensive technology, has an important role in employment generation and can lead to socio-economic upliftment of the society besides the addition of green cover with superior plants.

Conclusion

A commercially feasible technology for micropropagation of teak has been developed. The concept which was conceived in early 80's took almost two decades to realize to a commercial status. The technology has to be verified at laboratory and field levels before a commercial status is achieved. The field trials have demonstrated that specific clones have emerged out as the best performers at varied agroclimatic zones, whereas other clones confirmed that they perform better in their native geographical or agroclimatic locations. These studies have confirmed that micropropagation of teak can lead to production of high quality planting stock. The technology is available, however, industries should come forward to exploit the available knowledge and complement the existing plantation programmes. There are many tissue culture companies selling propagules at high price but the produce is associated with questions about the growth performance and uniformity in the field. Our studies have demonstrated that the source of explant plays a crucial role, i.e., the budwood material should come from a proven mother tree (preferably from terminal branches), the minimal media containing low concentration of plant growth regulators should be optimized and proper nursery practices should be followed so as to avoid abnormal growth patterns of the tissue culture propagules. Germplasm tagging using molecular markers would assist in ensuring the clonal fidelity of mother clone and progeny. Considering the potential of mass propagation of teak using tissue culture, care should be taken in selection of mother clones and a mixture of different clones should be used in large scale plantations to avoid monoculture. In future, tissue culture in combination with marker assisted selection and genetic engineering has great potential for improving the existing germplasm of teak.

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Soil management in teak plantations

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Abstract

Chemical and biological fertilization have been suggested as remedies to resolve the crisis of site deterioration in forest plantations. However, there have been few experimental studies on nutrition and other aspects of soil management of teak. Results of chemical fertilization studies on teak are also inconsistent. Most of the reported studies do not go beyond spasmodically evaluating height, diameter and/or basal area responses of trees over short intervals. Despite this, fertilizer application is routinely recommended for intensively managed teak stands. A limited number of replacement series experiments indicate that N-fixing trees improve growth of associated teak and soil nutrient concentrations. Such mixtures presuppose complementary resource use and grow well with minimal inputs even in degraded sites.

Keywords: Mineral nutrition, N-fixing trees, species mixtures.

Introduction

Establishing forest plantations to meet the ever-increasing wood requirement of the society has gained acceptance since the beginning of the industrial revolution. Teak (*Tectona grandis* L.f.) accounts for about 75% of the world's high-quality tropical hardwood plantations (Keogh, 1996). About 92% of the global teak plantations are in tropical Asia, while 4.5% is in tropical Africa and about 3% is in Central and South America (Bhat and Ma, 2004). Important teak growing countries include India (44% of the global teak area) and Indonesia (31%). Teak growth and productivity show considerable variability depending on stand age, site characteristics, density regimes, and rotation length both within and across different geographical zones. Relatively high mean annual volume increments (MAIs) of up to 20 m³ ha⁻¹ have been reported from Indonesia and low values of 2 to 7 m³ ha⁻¹ for India (Bhat and Ma, 2004). In Central America, for a plantation with rotations of 25 to 28 years, yields of 10.2 to 13.3 m³ ha⁻¹ yr⁻¹ have been reported (Arias, 2005).

Although teak prefers fertile, deep riverine alluviums (White, 1991), commercial considerations and the desire to enhance overall profitability from the land have led to the extension of teak farming into sites which are probably less suitable, which would probably explain the lower productivity of the species in some situations. Promotion of short rotation and/or poor site plantations has also raised concerns about sustainability. Of particular concern is the threat that frequent harvest-related nutrient exports could result in soil fertility deprivation and productivity. Loss of nutrients during harvest of short rotation plantations may far exceed the rate of replenishment by weathering of minerals in soils or by input via precipitation (Goncalves *et al.*, 1997). Further losses may occur due to inter-rotation site management practices such as slash and burn, site preparation, etc. The uncertainty, therefore, is: can teak (other plantations too) be grown perpetually on the same site without risk to their vigour and rate of growth?

Low organic matter inputs into the soil and the consequent decline in mineralization of organic nutrients is yet another concern in teak plantation management. Consequently, a progressive degradation of continuously teak-grown sites has been reported (Balagopalan *et al.*, 2001; Kumar, 2005). Furthermore, with global warming and the

resultant accelerated soil organic matter (SOM) oxidation, degradation of these nutrient-poor tropical soils will be faster. Silvicultural techniques such as application of chemical fertilizers and/or intercropping N-fixing plants are often recommended to augment soil nutrient availability. This paper attempts to review the literature relating to soil management aspects of teak including the use of biological nitrogen fixation to promote sustainability of teak plantations.

Mineral nutrition of teak

Teak occurs naturally on fertile soils derived from limestone, basalt and alluvium (Tanaka *et al.*, 1998) and reflects the high nutrient requirement, especially with regard to Ca saturation of the soil (Craven *et al.*, 2007). Plantation teak, however, is grown on a variety of soil and site conditions including the acid ferralitic soils of West Africa where P and K deficiency symptoms such as chlorosis, necrosis, and dieback are frequent (Zech and Kaupenjohann, 1990). Stunted growth caused by nutrient deficiencies is typical in several areas of Philippines (Zech, 1990). Drechsel and Zech (1994) using Diagnosis and Recommendation Integrated System (DRIS) concluded that N, Ca, and P were most deficient on the high productivity sites of Benin, Cote d'Ivoire, Liberia, Nigeria and Togo, while in 45% of all stands there was a relative Al excess.

It is widely believed that intensively managed plantations (high density) are expected to place large demand on soil nutrient reserves. However, the extent of scientific studies on teak nutrition has been disproportionately lower than what the economic value, ecological benefits, and/or silvicultural importance of the species would warrant (Kumar, 2005). Although nutritional studies on teak were initiated as early as 1933 in Java (Coster, 1933; Drees, 1940) and 1934 in Nilambur (Schnepper, 1934), there are surprisingly few published reports on teak plantation fertilization. The CAB abstracts (1939 to present) lists only less than 25 studies on this aspect (excluding those on teak nurseries). Other aspects of soil management in teak also have been inadequately studied.

A plausible explanation for the fewer number of teak fertilization studies is that many early authors found fertilizer application had little or no beneficial effect on teak growth. For instance, Drees (1940) reported that application of ammonium sulphate, potassium chloride, and slaked lime did not favour teak growth. Briscoe and Coronado (1971) stated that neither height nor basal area was significantly influenced by added N, Ca or Mg for 3- to 16-year-old teak in Puerto Rico. In another trial at Chiengrai, Thailand, height and radial growth increments of 10-year-old teak trees treated with ammonium phosphate (2.1 kg tree^{-1}) were not significantly different after one year (Thaiutsa *et al.*, 1976). Likewise, application of nutrients at 50:25:25, 100:50:50 and 150:75:75 kg N, P_2O_5 and $\text{K}_2\text{O ha}^{-1}$ (Gawande, 1991) and urea at 100, 200 and 300 g/plant (Bheemaiah *et al.*, 1997) did not result in significant growth responses in five-year-old teak in Kerala and 2.5-year-old teak in Andhra Pradesh, respectively.

Lack of fertilizer response may be explained on the basis of three factors, which may operate either separately or in unison. First, fertilization may enhance the growth of competing understorey vegetation, especially in young stands. This, if happens, may curtail growth through limiting availability of not only those nutrients supplied, but also suppressing the availability other site resources (moisture and light). Second, chemical fertilizers in general and N in particular, enhance the palatability/nutritional quality of the leaves and twigs, in turn, increasing herbivory pressure. Thus, it is probable that heavily

fertilised stands experience greater pest incidence, suppressing growth response.

Thirdly, if the inherent mineral nutrient supplying power of the site is high, then there may be little response to applied fertilizers. Interestingly, when favourable responses were observed, this was on poor sites (Drees, 1940; Ananthapadmanabha *et al.*, 1998). In addition, there may be long-term increase in soil fertility of repeatedly fertilised sites, as the nutrients stored in organic matter are released at an increased rate (Thomas *et al.*, 1998). This increased rate of nutrient recycling will reduce the use efficiency of inorganic nutrients and may also lead to their reduced retention, especially under low SOM levels. Other factors such as nutrient immobilisation and/or leaching may be important in stopping the fertilizer response. However, published reports seldom contain such details as soil fertility changes of continuously fertilised stands and the extent of nutrient immobilization/leaching.

Positive responses to fertilizers

Despite such lack of response to applied fertilizers reported by many, some authors (e.g. Schnepfer, 1934; Bhatnagar, 1969; Briscoe and Coronado, 1971; Prasad *et al.*, 1986; Kishore, 1987; Singh, 1997) demonstrated that teak growth and basal area increment are positively correlated with nutrient additions. However, in some studies which report positive influences of added nutrients, the effects were not consistent for all parameters evaluated. For instance, Kishore (1987) reported that diammonium phosphate (DP) significantly increased height growth of teak in the first two years after establishment, but no perceptible increase in radial growth was observed. In another study on continuous fertilization (for 5 years) of 10- and 20-year-old teak plantations with 0, 150 or 300 kg ha⁻¹ N and 0, 75 or 150 kg ha⁻¹ P, though height and diameter increased in both plantations, volume production increased only in the 10-year-old plantation (Prasad *et al.*, 1986).

Regarding rates, methods, and sources of P to teak, Kishore (1987) found that DP (80, 120 or 160 g) applied in circular ditches 10 cm deep and 20 cm from each plant significantly increased height growth in the first two years after establishment. Torres *et al.* (1993) working on alluvial sites with moderate drainage in Venezuela, found more diameter and height growth for two-year-old plantations when a fertilizer dose of 740 kg ha⁻¹ (28% P₂O₅, 39% CaO) was applied, compared to 0 and 370 kg doses. Gogate *et al.* (1995) after a critical assessment of a series of high input teak plantations observed that irrigation in conjunction with NPK fertilizer (50 g per plant annually for three years) gave positive height and girth responses. Likewise, height, diameter and biomass accumulation of five-month-old teak fertilized with N (100, and 200 kg N ha⁻¹) and P (150, and 300 kg P₂O₅ ha⁻¹) fertilizers, 12 months after treatment in Malaysia showed a significant increase compared to unfertilized control (Abod and Siddiqui, 2002).

Although positive response to the fertilizer applied in conjunction with thinning is expected, such studies are conspicuously absent in teak. Most reported studies evaluating fertilizer effects on teak also do not go beyond spasmodically evaluating height, diameter and/or basal area responses over short intervals (one or two years). There has been seldom a study on changes in soil organic matter dynamics, changes in site nutrient capital, tree/stand leaf area index and/or canopy coverage/thinning *vis-a-vis* nutrient relations over successive rotations. Despite this, fertilizer application to teak has become a common practice in recent years. In particular, application of 163 kg urea, 375 kg Mussoorie rock phosphate, 145 kg Muriate of potash, 105 kg quicklime and 373 kg of

magnesium sulphate per ha has been recommended (Balagopalan *et al.*, 2001) for young plantations in Kerala (two splits in the first year and four splits during second and third year). Application of 30 to 40 g N, 15 to 20 g P₂O₅, and 15 to 20 g K₂O per plant per year during 2 to 5 years of plantation age and thereafter once in 3 to 4 years for 10 to 12 years also has been recommended (KAU, 2002). In agroforestry situations, however, if the intercrops are fertilized, chemical fertilizers for teak can be reduced or skipped.

Biofertilizers

Biofertilizers have the potential to stimulate teak growth and survival especially on harsh sites. Experimental studies in West Java indicated that arbuscular mycorrhiza fungi (AMF: *Glomus aggregatum*) promoted growth of three-month-old teak seedlings (Irianto and Santoso, 2005). Although inoculation with phosphobacteria+AMF increased the survival and growth of teak seedlings, *Azotobacter* gave the best performance with respect to shoot length, shoot weight, and leaf area (Swaminathan and Srinivasan, 2006). Synergistic effects of soil management practices such as irrigation, drainage, and application of biofertilizers also have been reported. Application of calcium nitrate (CN), DP or CN + DP (250 kg ha⁻¹), with inoculation of *Glomus caledonium* or composite teak rhizosphere VAM (250 to 300 spores/100 g soil) showed better height growth and foliar N and P levels on a poor site, two years after treatment (Ananthapadmanabha *et al.*, 1998).

Species mix involving nitrogen fixing trees

As N losses are likely to be very important in plantation production systems, new systems of management which mimic the natural ecosystems where significant quantities of N are added via the biological fixation pathway, assume significance. Leguminous cover crops (e.g., *Centrosema*, *Calopogonium*, and *Pueraria*) and N fixing are particularly important in this respect. In addition to fixing about 150 kg N ha⁻¹ yr⁻¹, the loss of nitrate nitrogen via leaching was significantly reduced in systems involving cover crops (Sanchez, 1987). Yet another potential benefit of leguminous cover crops is soil conservation especially on steep slopes in the high rainfall zones of the tropics. Although cover crops are widely used in rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis*) and cacao (*Theobroma cacao*) plantations of the tropics, experimental studies involving them in teak are rare.

Use of woody legumes as a source of N nourishment to forest plantations also has considerable potential. Incentives for adoption of mixed species plantations as alternatives to monocultures may include economic considerations (increased productivity), plantation health (reduced losses due to disease and insect attacks), sustainability and diversification of wood products, besides greater C sequestration (Kumar, 2005). However, few experiments involving replacement series of N-fixing trees and teak have been published. In one such study on intercropping teak with *Leucaena leucocephala*, Kumar *et al.* (1998) reported that teak growth increased linearly as the proportion of *Leucaena* increased. At 44 months after planting, teak in the 33:67 teak-*Leucaena* mixture was 45% taller and 71% larger in diameter at breast height than those in pure stands. Using N₂ fixing trees thus could be a viable silvicultural option for stimulating early teak growth, especially on unfertilized sites. A 50% mixture (alternate rows of teak and N fixing tree) is considered optimal in this respect. The rationale is that in a conventional 50-year-rotation of teak, first mechanical thinning (removal of alternate diagonal rows) that reduces the density by 50% is carried out around the fifth year.

Therefore, teak density in a monospecific stand after the first mechanical thinning will be at par with that of a 1:1 teak-N fixing tree binary mixture.

Quality aspects of fast grown agroforestry teak wood vs conventional teak

Agroforestry, of late, is emerging as a principal land management system and a source of industrial wood. With more intensive management of the field crop components included in such systems (e.g., fertilization and irrigation), the associated trees also exhibit faster growth than a conventional teak monoculture. Consistent with this, Sharma *et al.* (2011) observed that teak growth was significantly better in teak+rice system than in pure plantation.

Timber quality of fast-grown teak from such systems, however, has been a source of debate. The prevailing dogma is that teak timber from agroforestry would be of inferior quality than conventionally grown teak wood. Bhat (2000) evaluated certain wood properties of fast-grown teak to determine the quality of timber from intensively managed plantations. Contrary to the general perception, fast-growing dominant (phenotypically superior) trees yielded a higher percentage of heartwood per tree during the juvenile period (up to 21 years), and the differences were not significant in the mature period (55 and 65 years). Faster growth also had very little effect on the strength of timber from 13-, 21-, 55- and 65-year-old plantations. Faster growth in relatively young forest plantations with judicious fertilizer application/genetic inputs thus can be advantageous in terms of heartwood volume per tree and timber strength. Juvenile wood from intensively managed plantations, however, may differ from traditional teak wood with respect to grain and texture, thus influencing the market value of the timber.

Conclusions

Despite the results of nutritional experiments on teak being largely inconsistent, fertilizer (chemical or biological) application in young stands prior to canopy closure or in conjunction with thinning operations, which open up the canopies in older stands, seems to be indispensable to sustain productivity. Although mixtures that include N-fixing species showed increased soil N availability in comparison to teak monoculture, quantitative estimates of nitrogen transfer between the legume and non-legume components are not available. Attempts should also be made to standardise the quantum of fertilizers to be applied under differing site qualities, periodicity (repeated annually or at longer intervals) and methods of application (broadcast, placement or banding), which have been neglected in the past, but is critical to avoid failure, minimise ecological damage and optimise the use of soil, water and energy resources.

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Forest-level management planning

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Abstract

A simulation-optimization approach for forest level management planning is discussed. First data are obtained for several treatment units (stands). Then a simulator generates, for each treatment unit a number of treatment schedules for a given planning period consisting of several subperiods. Then the optimal treatment combination is selected by solving a linear programming problem setting e.g. sustainability constraints. Discussion of the linear programming is based on the JLP and J software developed by the author.

Keywords: Forest Management, Optimization, Linear Programming, JLP software, J software, goal programming, simulation

Introduction

There are two main approaches to forest management planning: stand-level planning and forest-level planning. In economic terms, the basic method in the stand-level planning is maximization of the net present value. Maximization of the net present value presumes that all inputs and outputs have fixed known prices. Of special interest is the price of capital, i.e., the interest rate. It is assumed that there is perfect capital market, i.e., money can be saved and borrowed at the same interest rate in unlimited quantities. Even if we may conclude that stand-level planning generally, and maximization of net present value specifically is not sufficient, they form the basis of rational management.

In forest-level planning it is taken into account that there are connections between stands. The total utility of a given forest area is dependent on the total time patterns of all aggregated inputs and outputs on the area. Of course, in practice simplifying assumptions are needed for summarizing the planning situation.

The main phases of a planning process are:

- i). Data acquisition
- ii). Clarifying the criteria and preferences of the decision makers
- iii). Generating the alternative treatment schedules and predicting their consequences
- iv). Producing efficient production programs for the forest area
- v). Choosing the best production program according to criteria specified in (ii) (Kangas *et al.*, 2008)

In this paper, one forest-level planning approach is discussed. The proposed planning system consists of two components: i) a simulator and ii) an optimizer. Specifically the optimizer is based on linear programming. Two such systems are MELA system developed in Finland (e.g. Redsvén *et al.*, 2011) and GAYA/J system developed in Norway (see e.g. Rørstad *et al.*, 2010; Næsset *et al.*, 1997). GAYA/J has geographic information system interface. MELA system is using for optimization linear programming software JLP (Lappi, 1992) and GAYA/J is using the new software J (Lappi, 2005). JLP and J are specially designed for such linear programming problems which appear in

forest management planning. This presentation is based on the way optimization can be understood and done using JLP or J.

Simulation of Forest Development

The simulator in the simulation-optimization approach needs to generate all interesting treatment schedules for all treatment units (stands). The total planning period is divided into subperiods. Treatments are assumed to occur at the beginning or in the middle of each subperiod. During a typical growing phase, a special treatment is 'do nothing'. Other typical treatments are 'thinning with intensity x', 'clear cut', 'plant with x seedlings' and 'fertilize'. Between the possible treatment points, the development of each treatment unit is predicted using development models. Models are needed for diameter growth, height development, mortality, volume and timber quality. Also data on timber prices, harvesting and transportation costs and the interest rate are needed. These can be attached to schedules either at the simulation phase or at the optimization phase. The growth models can be either stand-level models (as in GAYA/J) or tree-level models (as in MELA). Treatment schedules form a tree structure. Schedules can be numbered according to terminal nodes. The J software contains also a simulator language which can be used to generate a simulator.

Optimization of Forest Treatments

After the forest simulator has simulated for a number of treatment units several treatment schedules, the 'best' treatment combination can be obtained by solving the following linear programming problem:

$$\text{Max or Min } z_0 = \sum_{k=1}^p a_{0k} x_k + \sum_{k=1}^q b_{0k} z_k \quad (1)$$

subject to the following constraints:

$$c_t \leq \sum_{k=1}^p a_{0k} x_k + \sum_{k=1}^q b_{0k} z_k \leq C_t \quad (2)$$

$$x_k - \sum_{i=1}^m \sum_{j=1}^{n_i} x_k^{ij} w_{ij} = 0, k = 1, \dots, p \quad (3)$$

$$\sum_{j=1}^{n_i} w_{ij} = 1, i = 1, \dots, m \quad (4)$$

$$w_{ij} \geq 0, i = 1, \dots, m, j = 1, \dots, n_i \quad (5)$$

$$z_k \geq 0, k = 1, \dots, q \quad (6)$$

where

m = number of treatment units (stands)

n_i = number of management schedules for unit i

w_{ij} = the weight (proportion) of the i th treatment unit managed according to schedule j

x_k^{ij} = amount of item k produced or consumed by i th unit if schedule j is applied

The problem is solved by finding proper values for the unknown variables w_{ij} , x_k and z_k .

Constraints 2 are for the aggregated variables and other decision variables of which the decision maker is interested. These constraints will be called utility constraints. Term 'constraint' without qualifications refers later to the utility constraints. Constraints 3 define the aggregated output variables x_k as the sum over the calculation units. Coefficients x_k^{ij} are known constants produced by the simulation system. If the simulation system computes output quantities per area unit, then coefficients x_k^{ij} are obtained from these relative figures by multiplying with the area of the unit. Constraints 3 can be equivalently written as

$$x_k = \sum_{i=1}^m \sum_{j=1}^{n_i} x_k^{ij} w_{ij}, \quad k = 1, \dots, p \quad (7)$$

The less intuitive form is used in (3) in order to follow the linear programming convention that the right hand side is always a constant.

Constraints (4) are so called area constraints saying that proportions of treatment schedules in a treatment unit need to sum up to one. A variable w_{ij} is called a w -variable or a weight. A variable z_k is called a z -variable. W -variables and z -variables are decision variables by which we can fix a possible solution. Even if aggregated x_k variables are formally unknown variables of the optimization problem, their values can be trivially computed from Eq. (7) if the values of w -variables are known. Z -variables and (aggregated) x -variables are utility variables that determine how good the solution is. As described by Kilkki (1987), all variables in a linear programming problem can be interpreted as variables in an implicit utility model.

It is assumed in the above problem formulation that the identity of treatment units is preserved throughout the planning horizon. Thus the planning model can be classified as type *Model I* in the *Model I / Model II* terminology (see, e.g., Dykstra 1984). Usually the definition (7) is directly written into (1) and (2), but I think the above formulation is more intuitive. Usually also linear programming forest management problems are written without z -variables. An example will be given where z -variables are needed.

The JLP and J software take automatic care of the constraints (3) defining the aggregated x variables, the area constraints (4) and the nonnegativity constraints (5) and (6). There are as many area constraints as there are treatment units in the data. The difficulty of solving a linear programming problem is generally proportional to the number of constraints. If number of treatment units is large, solving forest management planning problems may be impossible or may take much time, if a standard linear programming algorithm is used. JLP and J are using a special linear programming algorithm which is based on the generalized upper bound technique of Dantzig and VanSlyke (1967) by which one can get rid of the area constraints with some extra overhead cost. Thus JLP and J can solve extremely large problems with hundreds of thousands treatment units and millions of schedules, and large problems can be solved in seconds.

Sustainable Forestry

The most common problem formulations in linear programming forest management planning aim at sustainable forestry. Let there be 5 subperiods in the planning period. Let $npv.0$ be the total net present value discounted to the beginning of the planning period, and let $income.1$ be the net income during first subperiod, etc. Then a problem for sustainable forestry can be written in J command language as:

```
sust=problem()
```

```
npv.0==max  
income.2-income.1>0  
income.3-income.2>0  
income.4-income.3>0  
income.5-income.4>0  
/
```

Note that ' $>$ ' above means actually ' \geq '. The solution of the above problem guarantees that the net incomes are nondecreasing during the planning period. A problem is that the incomes may decrease substantially after the planning period. This is prevented by adding to the problem a constraint for the final state of the forests. A common constraint for the final state is:

```
npv.5-npv.0>0
```

which requires that the net present value of the incomes after the planning period is at least as large as the net present value initially. The simulator needs thus to be able to calculate the net present value of the incomes for each treatment schedule after the planning period. This can be done assuming that stand level optimization is applied at the final state, or after the planning period standard silvicultural recommendations are applied. Thus the simulator is doing computations also after the planning period, but there are no branching of schedules after the planning period. Another, more simple constraint for the final state is:

```
vol.5-vol.0>0
```

which requires that the volume at the final state is at least as large as the initial volume.

Goal Programming

Another example of a linear programming problem is goal programming. Let there be again 5 subperiods. Then the following J code defines a problem where the targets for incomes of subperiods are 800000 etc, and the constraint for the final volume is 50000000

```
gp=problem()  
sp.1 + sl.1 + sp.2 + sl.2 + sp.3 + sl.3 + sp.4 + sl.4 + sp.5 + sl.5==min  
income.1 -sp.1 + sl.1 = 800000  
income.2 -sp.2 + sl.2 = 850000  
income.3 -sp.3 + sl.3 = 900000  
income.4 -sp.4 + sl.4 = 1000000  
income.5 -sp.5 + sl.5 = 1100000  
npv.5 > 50000000  
/
```

The 'sl' variables are slack variables and 'sp' variables are surplus variables. This problem requires that the sum of absolute deviations from the target values are minimized. Deviations at different subperiods can also have different weights.

Domains

Often it may be useful to set constraints for a subset of treatment units. In JLP/J this can be taken care easily using 'domains'. A domain is a subset of treatment units (stands) defined using stand-level variables. For example, if distance_to_town is a variable telling the distance to the nearest town, it can be required that within a given distance the total volume there should be at least a given amount of standing volume using:

distance-to-town.le.15:

vol.1>2500

vol.2>2500 etc.

Solution of the Linear Programming Problem

The solution of the linear programming problem provides values for the weights of schedules, w_{ij} and the values of the z_k variables. Using the weights of the schedules, the values of the aggregated x -variables can be computed using (7). Note that the values can be computed for all x -variables simulated by the simulator, not just for those x -variables which appear in the linear programming problem.

If there are binding constraints there will be split treatment units in the solution, i.e., there will be weights which are between zero and one. Some consider this as a drawback in the linear programming approach. Requiring that each w_{ij} is either zero or one leads to integer programming problems which are considerably more difficult to solve. One practical solution is to round the obtained linear programming solution to an approximate integer solution by accepting for unit i that schedule for which the weight w_{ij} is largest.

In linear programming, shadow prices tell the marginal properties of the solution. More specifically the shadow prices of constraints predict what happens to the objective function when the right side of the constraint is increased by one unit. The shadow prices of the area constraints (4) tell how valuable the treatment units are compared to each other. The shadow prices of the constraints (3) tell how valuable different x variables are in the light of the solution. The reduced costs of z variables which have value zero at the solution tell how the objective function will change if we force the variable to get a nonzero value

Conclusions

An approach for forest level management planning based on simulation and optimization has been briefly outlined. This approach is widely used in Finland and Norway to make large scale forest policy analyses and also to make forest planning at company level. I suggest that it will be discussed if this approach would be feasible also for teak plantations. Topics that should be discussed are:

- i) Are there enough available data about plantations?
- ii) Are there available good-quality (stand level or tree level) growth models which take into account different treatments?
- iii) Can prices of inputs and outputs be predicted?
- iv) Is there a simulator available? If not, who would make it?

When a simulator is available, optimization can be done using J software.

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Health and sustainable management of teak stands

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Abstract

Teak (*Tectona grandis* L.f.) has been planted in over 36 countries across the tropical and subtropical regions in the Asian, African and American continents as well as many islands in the Pacific and Atlantic oceans. The insect pests of teak can be broadly classified as defoliators, stem borers and root feeders. Defoliators cause loss in volume increment in plantations as they feed on leaves. The most important defoliators are the lepidopterans namely, *Hyblaea puera*, *Eutectona machaeralis* and *Paliga damastesalis*. The borers belonging to the Lepidoptera include *Alcterogystia cadambae*, *Xyleutes ceramicus* and *Sahydrassus malabaricus*. The root feeders include white grubs belonging to the coleopterans. For most of the above pests data is not available on the economic impact except the information on the damage potential. *H. puera* is the only pest for which economic loss has been assessed based on the work done in Kerala. Accordingly effective biocontrol strategies involving a baculovirus have been developed and field- tested to manage this pest. However, no routine defoliator management is being practiced in any teak growing areas. Disease incidences are common in nurseries and plantations. Major diseases encountered are bacterial collar rot, bacterial wilt, pink disease, *Phomopsis* leaf spot, *Colletotrichum* leaf spot, leaf rust, etc. Chemical control is usually adopted for the management of such diseases.

Keywords: Insect pests of teak, defoliators, *Hyblaea puera*, stem borers, biocontrol, diseases of teak

Introduction

Teak (*Tectona grandis* L.f.) whose natural distribution was limited originally to some parts of South and Southeast Asia, is now one of the most widespread tropical tree species. Teak has been planted extensively, both within its natural distribution range and elsewhere in the tropics and subtropics. Over the years, it has been planted in over 36 countries spread across the Asian, African and American continents as well as in many islands in the Pacific and Atlantic oceans. The global area under teak plantations in 1995 was estimated at 2.25 million ha, most of it is in the Asian tropics (94%), followed by tropical Africa (4.5%) and Central and South America (1.5%) (Ball *et al.*, 1999). During the last decade, there has been an unprecedented intensification of teak cultivation, particularly in Latin America, promoted by commercial enterprises.

Teak is known to be infested by about 187 species of insects in India and neighbouring countries (Mathur and Singh, 1960). Majority of these insects are defoliators (78%), with a smaller number of sap feeders (8.5%), stem borers (4.8%), root feeders (4.8%) and inflorescence and fruit feeders (3.2%). Only a few are recognised as economically important pests in plantations. In this paper, insect pests and diseases of teak and their control are discussed.

Insect pests of teak

Defoliators

Hyblaea puera (Lepidoptera: Hyblaeidae)

Among the defoliators of teak, *Hyblaea puera* is the most widespread and serious pest. *H. puera* occurs in all countries where teak is indigenous (India, Myanmar, Thailand and Laos). According to the distribution map (CIE, 1982), *H. puera* is present in all the three tropical regions - Asia-Pacific, Africa and Latin America. Until recently, outbreaks on teak have been reported only from Asia. In Latin America, outbreaks of *H. puera* on teak are of recent occurrence. In Costa Rica, outbreak first appeared in 1995 in a commercial plantation and has progressively increased with about 600 ha infested in 1998 and some patches suffering total defoliation (Nair, 2001). In Brazil, in spite of the presence of *H. puera* for a long time and establishment of commercial teak plantations since 1971, it appeared on teak only in 1996.

Teak defoliator outbreaks occur almost every year in India, over extensive areas. Outbreaks are also known to occur in Myanmar and Thailand. During these outbreaks mainly during the early flushing period of teak, trees usually suffer total defoliation, sometimes repeatedly, and usually there is partial defoliation later in the growth season (Beeson, 1941; Nair, 1988). Annual outbreaks are also known to occur in Myanmar and Thailand. Studies in young teak plantations at Nilambur in Southern India showed that defoliation by *H. puera* caused loss of 44% of the potential wood volume increment (Nair *et al.*, 1985).

Although teak defoliator has been recognised as a serious pest for over a century, the growth loss caused by the defoliator was ignored when a 60-year rotation was adopted. In addition, most of the plantations were under public sector. Now there is an increasing interest among private commercial entrepreneurs to cultivate teak with short rotations of 20 to 30 years by intensive management. In this context, proper management of the pest has become very pertinent and inevitable.

H. puera also causes damage to teak in Bangladesh (Baksha, 1990; Baksha and Crawley, 1998), China and Taiwan (Nair, 2001), Malaysia (Tee, 1995), Papua New Guinea (Dun, 1955), the Philippines (Quiniones and Zamora, 1987), Solomon Islands (Bigger, 1980) and Sri Lanka (Tilakaratna, 1991). In Indonesia, *H. puera* is believed to cause one or more defoliations every year in most teak plantations, but systematically gathered data are not available. The details of infestation outlined by Kalshoven (1953) indicate that the dynamics of infestation is similar to that noticed in India. Outbreaks of the teak defoliator, *H. puera*, have recently occurred in Costa Rica and Brazil. In Costa Rica, outbreak first appeared in 1995 in a commercial plantation.

Early attempts to control the teak defoliator relied on natural enemies, particularly, insect parasitoids. Even though this concept (Beeson, 1941) was well promoted aggressively over half a century, it was never practiced beyond experimental attempts. Chemical pesticides have been tested for controlling teak defoliator in India and in Thailand during sixties. However, chemical pesticides were not favoured for environmental reasons.

Use of Bacillus thuringiensis (Bt): Commercial formulations of the bacterium, *Bacillus thuringiensis* (Bt) have been found effective against *H. puera* in laboratory tests as well as in field trials (Kerala Forest Research Institute, unpublished). It has been used in

India in research plots as well as, to a small extent, in some private plantations. In Thailand, aerial application of Bt has been made in high value plantations and seed orchards (Chaiglom, 1990). The high cost of aerial spraying and comparatively high cost of the commercial product have prevented its wider use in the developing countries.

A nucleopolyhedrovirus causing disease in *H. puera* was isolated in 1988 in India (Sudheendrakumar *et al.*, 1988). Technology is now available for mass production, formulation and field application of the viral product for management of the teak defoliator (Nair *et al.*, 1996, 1998; Sudheendrakumar *et al.*, 2001, 2006)

Eutectona machaeralis (Lepidoptera: Pyralidae)

Outbreaks of the teak leaf skeletoniser, *E. machaeralis*, is known to occur in India and Myanmar. In Madhya Pradesh regular outbreaks of this pest have been observed. In Kerala although the insect is present throughout the year in small numbers, outbreaks occur towards the end of the growth season before normal leaf shedding. *E. machaeralis* infests teak in Bangladesh (Baksha, 1990), China (Li, 1992), Sri Lanka (Bandara, 1990), and the Philippines (Quiniones and Zamora, 1987).

Paliga damastesalis, a species very similar to *E. machaeralis*, has been reported as a major pest of teak in Java (Nair, 2000). No primary data are available on the frequency and intensity of its incidence. This pest is also known from Malaysia (Intachat, 1998) and Andaman Islands in India (Veenakumari and Mohanraj, 1996). In Thailand, defoliation by this insect has been recorded in the Southern peninsular region (Chaiglom, 1990). Other minor leaf feeding insects on teak in Malaysia include the curculionid beetle, *Hypomeces squamosus* (Tee, 1995) and *Acherontia lachesis* (Lepidoptera, Sphingidae) on seedlings (Pearce and Hanapi, 1984).

Control: The need for controlling teak skeletonizer is yet to be established. In Kerala the impact of *E. machaeralis* infestation on growth of teak has been ruled out as the infestation taking place during the leaf shedding season may not affect growth of the trees (Nair *et al.*, 1985). However, the situation in the drier areas like Madhya Pradesh may not be the same. Detailed information of the population dynamics of the insect is yet to be gathered both in India and other Asian countries. The correct identity of the insect is also required to establish whether *E. machaeralis* and *P. damastesalis* are one and the same or different.

Stem borers

Alcterogystia cadambae (Lepidoptera: Cossidae)

Alcterogystia cadambae (Moore) (= *Cossus cadambae* Moore), generally known as the teak trunk borer, is a serious pest of teak in southern India which has recently assumed major pest status in several plantations in Kerala, Tamil Nadu and Karnataka States. In Kerala, infestation by *A. cadambae* is noticed mostly in plantations adjacent to human habitations (Mathew, 1990). Trees growing in such areas are frequently subjected to mechanical damages due to lopping of branches, plucking of leaves, etc. Such trees are more susceptible to attack by the borers as the mechanical injury leads to formation of callus growth over wounds or profuse growth of coppices which offer conditions favourable for the initial establishment of this insect. A sample survey carried out in 48 selected plantations in Kerala revealed that the incidence varied from 3 to 58%

of the plantations. The damage intensity of affected trees also showed an increase with age. This was because the affected trees were subject to reinfestation over the years. Preventive methods recommended for controlling the infestation include : (i) clear felling of all badly affected teak trees to avoid further deterioration and to prevent further multiplication of the pest, (ii) extraction of all trees with low infestation at the time of routine silvicultural thinning, and (iii) enforcing measures to prevent mechanical injuries to the trees like lopping of branches, plucking of leaves, etc in plantations especially in areas prone to infestation.

Xyleutes ceramicus Walker (Lepidoptera, Cossidae)

The beehole borer, *X. ceramicus* Walker (Lepidoptera, Cossidae) the most serious among the stem borers found in Myanmar, Northern Thailand (Chaiglom, 1990) and in central Java (Nair, 2001). *X. ceramicus*, is also present in Sabah, Malaysia where 5 - 16% of trees were attacked (Tee, 1995). It does not occur in India. One of the reasons for the beehole borer outbreak is the disturbances occurring in the teak stands such as fire. Measures to avoid fire in the stands would reduce the infestation. Maintenance of stands without fuel loads is suggested to prevent fire in the stands. Severely infested trees could be removed by thinning.

Sahyadrassus malabaricus (Lepidoptera: Hepialidae)

Teak sapling borer, *Sahyadrassus malabaricus* is a minor pest of teak in India. In Myanmar and Thailand, a related species, *Phassus signifer* has been recorded on teak. The moths are large and grayish brown with a wing span of about 11cm and body length of about 5.5 cm. Early larval instars appear to develop in ground vegetation before they migrate to saplings. When established on saplings the larvae excavate a long cylindrical tunnel along the pith. At bottom the tunnel usually extends into the tap root, particularly if the sapling is small. The mouth of the tunnel is covered by a dome-shaped mat-work. The presence of mat-cover is a conspicuous sign of infestation by the borer. The larva feeds on the callus tissue that develops around the tunnel mouth. In some instances the bark is browsed in a ring around the entire girth of the sapling. Very rarely the entire thickness of the bark is eaten resulting in death of the portion above the ring. Some of the saplings break at this point. The life cycle is thus annual.

Study carried out by Nair (1982) has revealed the status of the pest in teak plantations in Kerala. A positive relation between the weed growth and pest incidence in plantations was evident. It is a conspicuous pest in some young plantations, although the overall damage caused, in general, is not serious. Pest management becomes necessary in experimental plantations and orchards where each sapling is important. Among the insecticides tested, 0.5% (0.125% ai) of Ekalux 25 EC was found to be the most effective ensuring complete control.

Root feeders

White grubs

Grubs of the beetles of the genus *Holotrichia* (Coleoptera: Scarabidae) generally known as white grubs have been recorded as major pests on teak seedlings in nurseries (Mathur and Singh, 1960). In the last few decades, incidence of white grubs on teak has

increased (Thakur, 1988, 1993) possibly due to large-scale production of teak seedlings, grown in an agriculture-like ecosystem (Kulkarni, 2006).

H. consanguine, *H. insularis* and *H. serrata* are known to damage teak nurseries in Maharashtra, Orissa and West Bengal (Sen-Sarma and Thapa, 1981). *H. fissa* infests teak nurseries in Kerala (Varma, 1991) causing 20 to 30% mortality of seedlings. Infestation of the white grub, *Schizonycha ruficollis* (Fabricius) has been reported in teak nurseries in Maharashtra during May- September (Kulkarni *et al.*, 2007). White grubs infestation in teak nurseries has also been reported from other countries including Indonesia (Nair, 2001), Bangladesh (Baksha and Islam, 1990) and Sri Lanka (Bandara, 1990). Effective control of white grubs can be achieved by treating the soil in the nursery beds with Phorate 10G (20g and 30g/bed) or Carbofuran 3G (70g and 100g/bed) before sowing the seeds (Varma, 1991).

Diseases of teak

Teak is susceptible to various diseases at nursery and plantation stage (Sharma *et al.*, 1985; Bakshi *et al.*, 1972; Jamaluddin *et al.*, 1986). The important diseases recorded on teak are the following.

Bacterial collar rot

Bacterial collar rot disease caused by *Pseudomonas* sp. is generally recorded in young seedlings in teak nurseries. In the affected seedlings, initially the collar area just above the ground shows a slight shrinking. At this stage, the top leaves become flaccid and drooped. When the affected area turns blackish-brown and gets further constricted, the seedlings show scorching of leaves with pronounced symptoms of wilting. The wilted seedlings die soon. The disease can be controlled by application of Plantamycin 0.01% (a.i.).

Leaf blight

Infection is prevalent in nurseries. The infected plants show water soaked grayish brown patches that enlarge rapidly and cover a large part or the entire lamina. The blighted leaves often show holes in the infected portion as a result of shedding of infected tissues during heavy rains. The infected leaves dry up and are eventually shed. The disease spreads laterally in the nursery through overlapping foliage of the adjoining seedlings often resulting in group blighting of seedlings. In each case of severe infection, defoliation is high. Immediate removal of infected plants helps to prevent the disease spread. Application of Dithane M-45 (0.1%) is found effective in controlling the disease.

Bacterial wilt

Bacterial wilt caused by *Pseudomonas solanacearum* usually occurs in young teak plantations varying from 6-month-old to 2-year-old. The disease manifests during warm and wet period, especially just after the onset of monsoon. The infection usually occurs through injury and occasionally through lenticels. The symptoms, characteristic of vascular wilt disease, are expressed in the following dry period. The bacterium causes systemic infection of vessels, which show necrosis and discolouration.

The development and spread of the disease can be controlled to a considerable extent by adoption of proper sanitation methods. The affected plants should be uprooted

carefully and burnt. Planting in water-logged areas should be avoided. As the disease is easily manifested through an injury to the root system, utmost care should be taken during weeding and soil working operations. For casualty replacement, the planting should be done in a separate pit dug away from the site of the infected plant. The soil at the site of the infected plant should be drenched with Plantamycin 0.01% (a. i.).

Pink disease (Stem canker)

The pink disease of teak commonly occurs in all parts of the State where high rainfall (ca. 3000 mm per annum) is received. The disease may become serious in 1- to 5-year-old teak plantations where the terminal shoot is killed, consequently affecting the height growth. Pink disease of teak has been recorded from Karnataka (Bakshi, 1975) and Kerala, India. The disease is characterised by a pink encrustation over a canker, formed at the site of infection on the stem.

Application of Bordeaux mixture (10%) is effective in controlling the canker disease. However, in severely cankered stem, application of a systemic fungicide like Calixin (tridemorph 0.1% a.i.) with a spreading agent would be more effective.

Phomopsis Leaf spot disease

This is one of the most common leaf diseases of teak in Kerala. The organisms include *Phomopsis tectonae* and *P. variosporum* (first record from Kerala). The damage potential is high in nurseries. Leaf spots appear during August/September and infection continues till November/December. The leaf spots cause considerable damage to the photosynthetic area. Where more than 50 per cent of the area is covered with necrotic lesions, leaves are defoliated prematurely. Hence more serious impact in nurseries is observed.

Colletotrichum Leaf spot disease

Colletotrichum state of *Glomerella cingulata* (Stonem.) Spauld. & Schrenk is a common pathogen having a wide host range including teak (Sharma *et al.*, 1985). The leaf spot disease is of common occurrence in plantations. It usually appears on mature leaves during the monsoon (July/August). Trees of all age groups are susceptible to this disease. Irregular leaf spots, light to dark brown in colour, with a pale margin are usually found on mature leaves. The individual spots coalesce to form large irregular spots, which cause drying up of leaves and consequently premature defoliation.

Leaf rust

Teak leaf rust caused by *Olivea tectonae* is widespread in nurseries as well as in plantations, especially in dry areas. Though the rust occurs almost round the year, it is most prevalent during August to January/February. The upper surface of affected leaves shows scattered dull green flecks corresponding to the orange yellow uredinia on the lower surface. These flecks turn necrotic in due course and appear as small brown spots. Severe rust infection causes premature defoliation in nurseries and young plantations, which possibly affects the growth. Application of foliar sprays of sulphur-based fungicides is recommended.

Powdery mildew

Powdery mildew of teak caused by the fungus *Uncinula tectonae* Salm. occurs in teak plantations of all age groups but mostly in plantations of age above 15 years. Symptoms include irregular white patches, consisting of mycelium and asexual conidia, developed on the upper leaf surface towards November /December just before the senescence. These patches coalesce and cover the entire surface of the leaf giving greyish-white powdery appearance. Severely infected leaves are defoliated prematurely. Sulphur dust is found to be the most effective fungicide in controlling *Uncinula tectonae* on 2-year-old seedlings followed by Baycor (triadimenor), Morestan (quinomethionate) and Calixin (tridemorph) (Kulkarni and Siddaramaiah, 1979).

Heart rot

Heart rot is the greatest single cause of damage to forest trees including teak. Harsh and Tiwari (1995) have estimated that nearly 38 to 88% teak trees are affected by heart rot entailing an average loss of about 11% in wood volume in Madhya Pradesh. *Perenniporia tephropora* (Mont.) Ryv. and *Phellinus caryophylli* (Cooke) Ryv. have been found to be the causative fungi.

Phanerogamic parasites

Dendrophthoe falcata var. *pubescens* Hook. f. c (Loranthaceae) is the most common and harmful mistletoe - an angiosperm parasite found in teak plantations throughout Kerala. In Nilambur Forest Division, Kerala almost all teak plantations above the age of seven years are being attacked by mistletoes. Though several species of angiosperm parasites occur on other tree species adjacent to teak plantations, their presence on teak is negligible showing host preference. Heavy infestation results in death of trees.

Mechanical removal of the parasite by lopping of the infested branches was practiced earlier in Kerala which has been given up due to heavy labour cost. Tree injection of selective weedicides had been tried with partial success (Ghosh *et al.*, 1984).

Conclusions

Although teak is a host to many insects, only very few of them are considered to be serious pests of economic importance. The feasibility of management of the pests depends on the infestation characteristics particularly the feeding pattern. The defoliators are comparatively more amenable to control compared to the borers. Defoliation being a visible process, timely control measures can be easily adopted. However, infestation by borers like *Alceterogystia cadambae* becomes visible only at later stage of infestation. The impact would be severe due to borers causing multiple infestations. In most cases of borer attack, successful control methods are lacking except silvicultural recommendations. Among the defoliator pests, *H. puera* ranks first. Viable recommendations are available for management of the pest which include use of the baculovirus pesticide. The productivity of teak plantations depends on better management including pest control.

Management of diseases is necessary to minimize the loss which can be achieved through chemical, biological, cultural and silvicultural measures. The diseases in nurseries and plantations are being controlled through different management practices like use of quality seeds, modification in cultural practices, use of graded seedlings for

plantations, proper plant density, silvicultural measures, eradication of infected root stumps and alternate or collateral hosts, use of resistant species, biocontrol through mycorrhizae, antagonistic microorganisms and hyperparasites, and use of fungicides (Jamaluddin, 1995). An integrated approach would be ideal for disease management in nurseries. The strategies include avoiding, excluding and eradicating the pathogen; protecting the host from infection; developing resistant hosts and killing the pathogens in infected hosts. Integration and manipulation of all the available control measures to get healthy plants in keeping the disease below the economic threshold level at an effective cost is, therefore, required for overall management of tree species.

In the global perspective, the pest/disease management issues in teak plantations appear to be a major concern of forest entomologists than farmers. A serious thinking to apply the knowledge in management practices is required if higher productivity in the plantations is a concern of the farmers. Low productivity experienced in many plantations could be due to various reasons. Hence an integrated teak plantation management strategy including the pest/disease management would be ideal to enhance teak productivity. It is a fact that quantification of the loss caused by many pests/diseases at the species level as well as regional/country level is required to identify the pest/disease worth controlling and to convince the teak growers.

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Scope for innovative utilization of teakwood

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Abstract

The reference of use of teak in Indian history dates back to more than 2000 years, where teak planks were used in caves. From 7th century onwards, teak was one of the known timbers for its use in maritime purposes. Before empirical research came into being, the multiple uses of teak were known in countries where it occurred. Teak is considered as paragon among timbers. The virtues of the timber based on structural, physical, mechanical and chemical properties, working qualities and uses based on scientific data generated, are presented in this paper. There is no use left out where teak has not been tried. Teak wood is used in an innovative way mostly in furniture and handicraft sectors. Experiments have proved that teak sawdust can be used for producing of activated carbon for removing dyes from synthetic effluents.

Keywords: *Tectona grandis* Linn.f, wood anatomy, physical and mechanical properties, wood processing, teakwood uses.

Introduction

Wood is one of the oldest materials used by man since time immemorial. Archaeological evidence of use of timber indicates that the ancient caveman had used the locally available trees for firewood around 20,000 years back. However, the actual evidence of use of wood came into being during the Mohenjo-Daro period. Experience through ages led to use of timbers based on their longevity (durability) where no empirical methods were available for testing and application. The strong and durable timbers were considered auspicious for many purposes and weak and non-durable timbers were considered inauspicious. Teak (*Tectona grandis* Linn.f.) which is one of the most preferred species has features, which no other timber possesses, and this must be the reason for its wide usage. Teak wood is unique in that it finds application in diverse end uses. The timber is attractive with golden brown colour and characteristic figure. It is moderately heavy, exceptionally durable against termites and easy to work. It lasts for hundreds of years in ship building and construction. In terms of the multiple uses, teak wood is the last word amongst the timbers. This paper addresses the fundamental aspects of teak wood from the point of view of its structure, properties, processing and utilization of the wood for innovative products.

General properties and gross structure

In teak wood, the sapwood and heartwood are sharply demarcated. Sapwood is white or pale yellow, heartwood is light golden-brown when fresh, turning brown or dark brown on exposure, often with darker streaks. The colour and markings of the heartwood vary considerably with locality. The wood is moderately hard and heavy, usually straight-grained but samples from the drier regions often exhibit rather irregular grain, coarse and uneven-textured. The wood has an oily feel and characteristic odour. The wood is ring-porous. Growth rings are distinct, generally conspicuous to naked eye except in extremely slow grown samples, less than 1 to 6 rings per cm. Vessels in the earlywood are large, distinctly visible to the eye, mostly solitary, oval in outline, partly filled with tyloses and sometimes with white powdery deposits, gradually becoming smaller towards the late wood. Latewood vessels are moderately large to small, mostly solitary or in radial pairs, round to oval in outline, vessel lines of the early wood zone conspicuous on longitudinal surfaces, parenchyma forming thin sheaths around the vessels, distinct only under the hand lens but distinct to the eye in the earlywood forming a continuous zone delimiting the growth rings. Rays are visible to the eye, distinct under the hand lens, moderately broad, somewhat widely spaced and uniformly distributed (Pukayastha, 1985) (Figs. 1, 2).



Fig 1. End- grain pattern showing distinct sap wood and heart wood; distinct growth rings and coarse texture of wood.

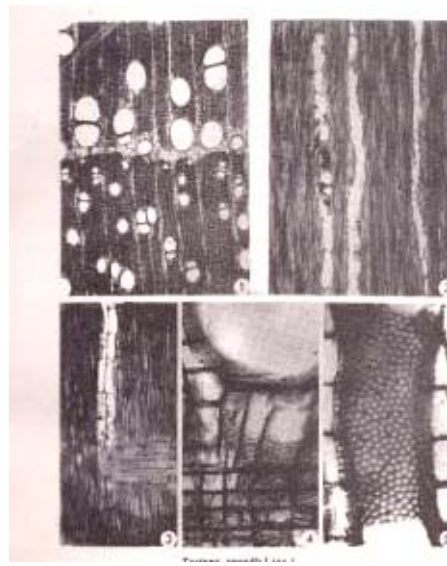


Fig 2. C.S showing ring porous condition T.L.S and R.L.S showing ray morphology; R.L.S showing ray-vessel pitting ; T.L.S. showing inter-vessel pitting.

Mechanical properties

Teak is generally described as a moderately hard, moderately heavy and strong timber. However, the air-dry weight of the consignments from different localities tested at FRI has been found to vary from 592 to 704 kg/m³ and the strength properties also exhibit more or less similar variation. Generally, the timber from the dry regions of Madhya Pradesh is about 10% lower in strength properties than that of moist regions of South India and there is no significant difference between-natural and plantation grown timber from the same locality. Work on some increment cores extracted from 36-year-old trees

of known seed origin grown in two different localities has shown that the locality has a highly significant effect on specific gravity while the variation due to seed origin is not significant. Similar studies made on trees grown on two different soils at North Raipur, Madhya Pradesh have indicated the specific gravity is somewhat higher in the trees grown on schist soil than of those grown on gneiss soil but the differences are not statistically significant.

Studies on relationship between the rate of growth and strength properties (Limaye, 1942) showed that the strength decreases with an increase in the number of growth ring per inch. In other words, slower grown timber tends to become weaker. The strongest timber is produced at a rate of growth of about 5 to 6 rings per inch (about 2-3 rings per cm). However, other studies have revealed that there is no significant correlation between ring width and either specific gravity or maximum crushing stress (Mukerji and Bhattacharya, 1963; Purkayastha *et al.*, 1972). As such, there appears to be no possibility of assessing the strength properties from measurement of rate of growth. Anatomical investigations have also shown that there is no definite relationship between ring width and proportion of tissues but a high correlation exists between fibre wall thickness and specific gravity as well as the maximum crushing stress. Studies on within the tree variation have indicated that the strength is generally higher in bottom and top portions of the bole and comparatively lower at intermediate heights. The lowest strength was found to be at a height somewhere between 5 and 8 m from the ground level (Sekhar and Negi, 1966).

Seasoning behaviour

Air-drying: Teak does not offer any difficulty in air-seasoning as it suffers very little or no damage from the usual seasoning defects. A slight end-splitting is found to occur but practically very little surface checking and warping. There are no signs of insect attack, discoloration or decay. End coating to prevent splitting is advisable. It should be stacked in open under cover with free air circulation through the piles.

Kiln-drying: In kiln-seasoning also, it does not offer difficulty, but it is rather slow in drying (Anon., 1956) and is reported to require more care in determining both the initial and final moisture contents, as variations in drying rates of some boards are occasionally great. Once dried, it is very little stable to changes in atmospheric humidity. A survey on seasonal variation in moisture content of some important woods at different localities showed that teak and sissoo, which are the best for furniture, show the least dimensional changes due to moisture variation (Rehman, 1942).

Solar Drying: Drying of teak by solar means has been carried out by one local researcher, who used a semi-green house type dryer. It takes 26 days to bring down the initial moisture content of 39.1% in 1- inch thick boards to 12. 2%. No drying defects were observed. It is thus observed that parquet blocks that are solar dried are quite satisfactory (www.baliTeakfarms.com/more-about-teak-wood.html).

Drying by girdling: It is a common practice in Myanmar, India and Thailand. In trees that have reached the felling age, the sapwood is removed and the tree is left standing, normally for three years. This is to allow the wood float during water transportation and at the same time reduce the drying time with less drying defects. Girdled teak that stands for 27 months has a moisture content of 33.6% still left in the wood. It is still

above the normal fiber saturation point and therefore it is only partially dry (www.baliTeakfarms.com/more-about-Teak-wood.html).

Shrinkage and Movement

The shrinkage and the specific gravity of teak from different origins are given in Table 1. It consists of both natural and plantation-grown teak, as well as girdled and green-felled teak. The specific gravities are on the basis of oven dry weight and green volume. Shrinkage data are from green condition to the oven dry state.

Table 1. Specific gravity and shrinkage of teak from different countries

Locality	Condition	Specific Gravity	Shrinkage %(Green to oven-dry)	
			Radial	Tangential
Myanmar	Green	0.586	2.1	3.0
Myanmar	Girdled	0.594	2.2	3.0
Malabar, India	Natural	0.614	2.5	6.0
Central Provinces, India	Natural	0.526	2.2	4.0
Bihar/Orissa, India	Natural	0.536	1.8	4.0
Honduras	Plantation	0.560	2.1	5.0
Philippines	Plantation	0.490	2.2	4.0
Thailand	Plantation	0.640	2.5	5.0
Indonesia	Plantation	0.646	0 - 2.0	0 - 3.5
Nigeria	Plantation	0.509	0 - 3.0	0 - 5.0
Papua New Guinea	Plantation	0.509	2.1 - 3.0	3.6 - 5.0
South Africa	Plantation	0.646	2.1 - 3.0	3.6 - 5.0

Source: www.baliteakfarms.com/more-about-teak-wood.html

It is observed that wherever teak is grown, the specific gravity is quite comparable except that of the Philippines. Similarly the shrinkage of teak from natural habitat is rather consistent and shrinkage from teak outside the natural habitat is rather high. Teak is thus classified as a timber with low shrinkage.

Seasoned timber in service is liable to shrink and swell in accordance with the Equilibrium Moisture Content of the locality. Results of tests carried out at the Forest Product Laboratory in Princes Risborough show that teak has a small movement, similar to rosewood. Movement is an important index for fine works, cabinet making and parquet flooring.

Natural durability

The heartwood of teak has a reputation of being one of the most durable timbers of the world. It is practically immune to fungi and termites though not so to marine borers. The wood work of the Forest Research Institute, Dehra Dun, which is of Burma teak, is in excellent condition even after 50 years. Chowdhury *et al.* (1967) who examined a sample of 2200 years old teak from Karla caves (Maharashtra), found it to be superficially sound although the chemical constituents were partly degenerated.

Study on the chemical constituents of the wood have shown that almost all the anthraquinones found in the wood are effective against termites, as are lapachols,

especially desoxylapachol. Tectol and dehydrotectol are ineffective against termites, and the anthraquinones are ineffective against fungi, but there are many indications that naphthoquinones, especially desoxylapachol, are fungicidal (Anon., 1967).

The outer heartwood is more resistant to both termite and fungal decay than the inner heartwood. From the point of view of termite resistance, the outer heartwood has been classed as very resistant (class I) while the inner heartwood is only resistant (class II). Investigations of wood from four provenances have indicated that termite resistance is genetically controlled (Sen-Sarma *et al.*, 1975). Similar experiments with two sets of trees grown in two different localities have shown that seed source is more important than the environmental factors (Sen-Sarma and Thakur, 1979). As regards the decay resistance, the outer heartwood has been found to vary from very resistant, to moderately resistant. In older tree (age of heartwood 54 -97 years based on ring counts) inner heartwood is less resistant than outer heartwood within the same sample. In young trees (age of the heartwood 11-47 based on ring counts) the entire heartwood of the sample is generally of the same resistance class and compares with the inner heartwood of older trees. Variation in decay resistance appears to be correlated with the age and the rate of growth of trees as well as the distance of the sample from the pith.

Graveyard tests conducted with samples from Madhya Pradesh gave an average life of 151 months with a minimum of 124 months and maximum of 160 months. It is possible that the samples were from small trees. Teak imported to India from different countries has also shown greater resistance under graveyard test conditions.

Working Quality

Teak is a easy to saw and work. It is not difficult to saw when seasoned, though somewhat liable to bind if cut by a thin-gauge saw in a green state. It readily lends itself to conversion either on a circular or bandsaw and a moderate gauge gives satisfactory results. It can be planed to a fair surface and planing with 25" cutter gives the best results. It is one of the best timbers for mortising, fairly good for boring but not so for turning. However, care is needed for end grain working as the timber is inclined to be brittle. Considerable bulk of this timber is being peeled although the cutting resistance is rather high, and due to the presence of silica, the knife gets blunt. Experiments conducted at the Forest Research Institute have shown that the cutting resistance decreases with increase in temperature and is fairly constant in the range 55 -75°C after which it rapidly increases. The smoothness of the veneers is also the best in this temperature range. Veneers of maximum strength are obtained at the knife angle of 90.5 - 91.2. On slicing it gives decorative veneers. The timber can be glued satisfactorily on freshly machined or newly sanded surface. Studies on the sanding quality of the timber have indicated that the wear resistance increases with the caoutchouc content and higher the content, smoother is the surface. Bending property of teak is rather poor and it can only be used for low curvature bends . It is also amenable to carving but not suitable for fine work. Teak does not corrode iron, copper, aluminium, etc. and has fairly good resistance against acids. It takes polish well and the percent gloss up to 85 can be achieved by the application of artificial films of finish. It takes nail and screws fairly well (Pukayastha, 1985).

Except the teak from drier areas of the country, the rest is quite easy to work in all aspects. The resulting surfaces of planing, boring and turning are smooth. Resistance to splitting when nailed is rather good. Tools tend to become dull in machining process

because of the presence of silica. Silica is said to be present in the vessel elements. Silica content in teak varies up to 1.4%. Teak from the northern part of Myanmar has slight fibre pricking in planing, and due to some cross-grained nature, it is not of good quality compared to that from other countries (www.baliTeakfarms.com/more-about-Teak-wood.html).

Utilization

Teak is considered to be the standard timber for joinery and furniture/cabinet making. In trade, the timber is classified into two types, viz., timber from South India especially from the Malabar coast (South Indian Teak) and the timber from the dry zone of Central India and Gujarat (commonly known as C.P. teak). Teak from the Malabar coast is usually straight-grained, lighter in colour and with few markings while that from the dry zone of central India is often darker and frequently marked with bold dark brown or almost black. The former type is generally preferred for constructional purposes and the latter is commonly used for furniture and cabinet making. It is extensively used for panelling and interior fittings. As flooring material, it is good for both strip flooring and block flooring, although not very good from the point of wear resistance. It is one of the most important timbers for ship-building. For deck covering it has been proved to be one of the best timbers in the world as it is not only durable and stable but also wears evenly. Because of its resistance to acids and alkalis, teak is used for vats, towers etc. in chemical plants, and also for wooden fittings in laboratories. Teak is largely used for making high grade and decorative plywood which is extensively used in furniture and cabinet making and specified for air-craft and marine plywood and for block boards. Teak wood is also used for textile and jute mill accessories, musical instruments and mathematical instruments. It is an approved timber for table tennis table, frame of carom boards, for general requirements of playground and park equipment. Teak poles are used for scaffolding, fence-posts and for overhead telecommunication lines (Purkayastha, 1985).

Innovative utilization of Teak

The virtues and the shortage of teak wood even for the purposes mentioned above restricts creation of innovative solid wood products. However, a lot of innovations are seen in product development in furniture, household items, artifacts and waste saw dust. Outdoor living is becoming popular and garden furniture is in large-scale production, where durable and light teak timber is much admired. There is also demand for its straight boles for use as used as masts, pillars or posts. Some of the products which are in current use like yacht flooring, bathroom roller wooden mats, temple models, outdoor furniture items, handicraft items are shown as below.





Hartono *et al.* (2005) found out that teak saw dust can be utilized for production of activated carbon under physical activation having microporous and mesoporous structure (pore size 0.6-100 nm). This can be employed as an adsorbent for dye removal from synthetic effluents. Since teak wood is used in larger scale in any part of the globe, the waste that becomes available from primary and secondary processing will also be available in good quantities. Applying the method suggested, it will be innovative to use the teak waste for this purpose.

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Teak plantations for climate change mitigation and eco system services

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Abstract

Ecosystem services are explained at local, global, and landscape levels. The set of factors fuelling climate change including demand for fuel, landscape fragmentation and degradation of natural and man-made ecosystems are elaborated. The linkage between ecosystem services and social well-being is described considering the different kinds of services such as provisioning, regulating services and cultural services.

The case of 'payments for ecosystem services' in Costa Rica is used to illustrate the possibility of monetizing of the ecosystem services and refinancing it for promoting local climate change mitigation measures. The ecosystem services from plantations are highlighted and linked to the concepts of REDD+. Carbon sequestration pattern in unmanaged stands, selection felling, long-rotation and shorter rotation systems is elaborated. The CO₂ FIX MODEL is explained in detail; further, the issues relating to biodiversity management in plantations and trade-offs between management options are considered.*

*Reconstructed from the rapporteurs' report as no abstract was received from the speaker.

Teak farms – a strategy for growth and job creation in rural Asia: Lessons learnt from Gunungkidul District, Indonesia

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Abstract

This paper discusses the development of teak farms and their roles in household economy based on the lessons learnt from the case of smallholder teak plantations in Gunungkidul District, Yogyakarta, Indonesia. Teak farms play important roles in household economy and contribute to the development of teak industries. The current condition however, limits the role of teak farms to farmers only as household saving accounts and part of their culture. Teak farms have not yet develop into more commercial business to trigger more growth and job opportunity. Smallholder teak growers are facing some difficulties to improve the economical benefits from their teak farms. Some strategies are recommended to improve these economical benefits, among others by intensive extension program to improve farmers understanding on applying proper silviculture practices; developing micro-credit institutions at village level to improve farmers' access to loan; improving market information and developing business collaboration between farmers' group and teak industries and by simplifying government regulation on timber transport document.

Keywords: Teak, smallholder timber plantation, household income, rural development, Gunungkidul

Introduction

Teak is among the most valuable timber species in Indonesia and used for many purposes. Teak timber is commonly used to produce furniture, housing materials, crafts, ships and many other products. The wood is durable, strong but easy to work, stable and performs beautiful color and figures. The specific gravity of mature wood ranges between 0.62 and 0.75 (Martawidjaja, 2005). For some of Indonesian ethnic groups, such as the Javanese people, teak has become part of their culture and the wood has a higher position as compared to the rest of other wood species in the country (Muhtaman *et al.*, 2006).

Demand for teak wood for both international and domestic always higher than its supply. With the assumption of per capita global wood consumption at about 0.54 m³/year, Keogh (2009) has estimated the total steady increase of world wood consumption from around 3.7 billion m³ in 2010 to 5.1 billion m³ in 2050. If the share of tropical hardwood timber to this global demand is maintained at 3.5%, the total demand for tropical hardwood timber will be around 97.9 million m³ in 2010 to 136 million m³ in 2050. As teak is the most dominant species for planted tropical hardwood timber, these figures more or less could represent the future demand for teak wood at global level.

For some regions in Indonesia, such as Java, teak farms have been playing important roles in developing rural areas. Teak farm business involves millions of farmers in rural areas on teak wood production and millions of others who work in the teak wood processing industries. For example, in Jepara alone, one of teak furniture industry center in Java, more than 15 thousands of small-scale industries were producing teak

furnitures, employing around 170 thousands of people and creating added value with the turnover of around Rp 12 trillion (about U.S. \$ 1.2 billion) per year. The total teak wood intake was estimated between 1.5 to 2.2 million m³/year (Roda *et al.*, 2007).

Two major teak wood sources are available in Indonesia, i.e. the industrial teak plantations which is mostly located in Java and currently managed by a state owned company "Perum Perhutani"; and the smallholder plantations which are spread across the country. While the supply of teak from industrial plantations are declining, share of smallholder plantations on teak supply is increasing. This increasing production of teak from smallholder plantations has become an important source of teak supply for furniture producers in Java.

The extent of smallholder teak plantations in Indonesia is poorly documented, although millions of household throughout the country are planting this wood species. The census which was conducted in 2003 revealed that the total household who own teak trees on their private lands has reached more than 3 million households. The total standing stock of teak trees managed by smallholders was around 80 million trees, where about 23% out of them was ready for harvest. Most of the plantations (about 63%) were located in Java. In Java, smallholder teak plantations concentrated in three provinces, i.e. Central Java (26,47 %), East Java (21,28%) and Yogyakarta (8,89 %), while outside Java the plantations was concentrated in Nusa Tenggara islands (the whole islands shared about 11.7% of the total population and 13.2% of the total harvestable trees), South Sulawesi (shared about 4.5% of the total population and 7.6% of the total harvestable trees) and Lampung (shared about 3.1% of the total population and 5.5% of the total harvestable trees) (Pusat Inventarisasi dan Statistik Kehutanan, 2004).

This brief article discusses the development and role of teak farms in rural livelihood. The content of paper is mainly based on lessons learnt from research project activities on smallholder teak plantations, completed by scientists from The Center for International Forestry Research (CIFOR) and its partners at Gunungkidul District, Yogyakarta, Indonesia. The study was funded by The Australian Center for International Agricultural Research (ACIAR) and has been commenced since July 2007 to June 2011.

The research project has three main objectives, namely: (a) to introduce farmers with silviculture techniques that can be applied on their teak farms to improve productivity and quality of the wood; (b) to develop a suitable micro-credit scheme for farmers to support their investment in teak plantation business and (c) to develop marketing strategies that provide better return to teak growers. The research is expected to provide impact on improving the economic benefits of teak plantation to farmers. The lessons learnt from this case study are expected to provide an overview of the potential of teak farms for rural development in various countries in Asia.

Teak farms in Gunungkidul District, Indonesia - a highlight

This section explains briefly the condition of teak farms in Gunungkidul District, Yogyakarta, Indonesia. The information would be useful for understanding the context of lessons learnt from the implementation of research on smallholder teak plantations in this region as described in the later sections. The adoption of lessons learnt from the region for application in other places therefore can be adapted to conditions in their respective areas.

The District of Gunungkidul is one of the five districts in the Province (Special Region) of Yogyakarta. The district is located between 7° 46'– 8° 09' latitude and 110° 21' – 110° 50' longitude (see Figure 1). The capital city of Gunungkidul District is Wonosari, which is located at 39 km to the southeast from the city of Yogyakarta. The district has 18 sub-districts 144 villages, and 1,536 *dusun* or hamlets, with the total area is 1,485.36 km² (Badan Pusat Statistik Kabupaten Gunungkidul, 2008).

The District of Gunungkidul is characterized by hilly topographic condition, where half of the region has slope area of more than 15%, in particular at the northern zone (Baturagung) and at the west, south, and east zones (Gunung Seribu). Only the central zone is relatively plain (Ledok Wonosari). The northern zone (Baturagung) lies at the altitude between 200 and 700 m above sea level. This area has relatively higher rainfall than the other parts and dominated by forest. The central zone (Ledok Wonosari) lies around the altitude between 150 and 200 meter above sea level and is the centre for agro-farming activities in the district. The southern zone (Gunung Seribu) lies at altitude between 100 and 300 meter above sea level and characterized by *karst* zone containing underground *karst* river system at a depth of 200 m. The average rainfall around the district is between 1,500 and 2,500 mm per year. Due to the *karst* condition, the rain water cannot be stored within the soil, but seeped fast into the underground river (Gunungkidul Regency. 2005).

Based on population census in 2000 and population survey in 2005, the total population in the district was projected at 685,210 people. About 66.5% of the total population was productive workers, where most of them (about 82%) were working as labor or family employee. Agriculture is the main sector for employment in the district. Gross Regional Domestic Product (GRDP) of the district in 2007 based on the current price was Rp 4,872,123 million, where 34% of this gross income was contributed by agriculture sector. The gross per capita income in 2007, based on the current price was Rp 7,110,408. Within the agriculture, the largest contribution is from food crops (64.05%), followed by forestry (27.27%), animal husbandry and its products (6.33%), plantation crops (1.69%), and fishery (0.66%).

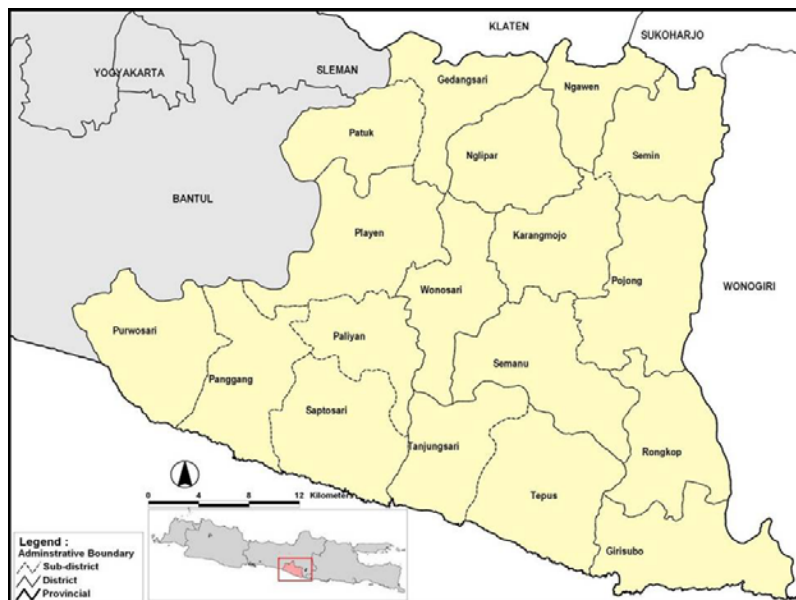


Figure 1. Map of Gunungkidul District

High population density limits the size of land ownership by farmers in the district. Based on household survey conducted in 2007 on 275 families (teak growers) in the district, the average land ownership per family was around 0.7 ha. Most of farmers (63%) occupy less than 1 ha of land or even less than 0.5 ha (37%). Only about 12% of farmers who manage land area of more than 2 ha (see Figure 2).

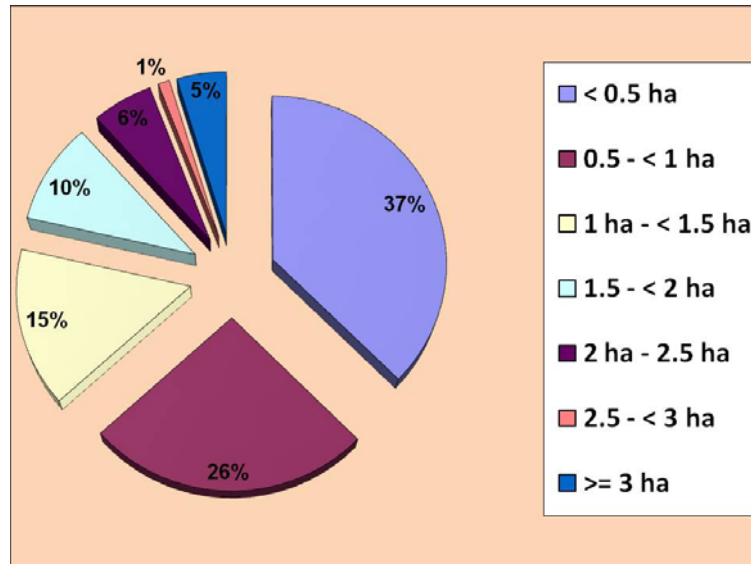


Figure 2. Land occupation of smallholder teak producers at Gunungkidul district

The district of Gunungkidul has been experiencing fast growing expansion on smallholder teak plantations. It was reported that in the 1950s, the district was among the most degraded areas in Indonesia with little forest cover of about 3% of its total land area (Filius, 1997). Smallholder teak plantations on private lands were initiated at around 1946 in the Pringsurat village, sub district of Nglipar (Sutarpan, 2005) and it widespread by the mid of 1960s (Filius, 1997). Sutarpan (2005) furthermore states that by the mid-1960s, the state owned teak plantations in Nglipar were heavily threatened by illegal logging, but teak on private land was safe and maintained. Personal communications with several senior farmers and key informants¹ revealed that smallholder teak plantations have attracted many farmers in the early 1980s. By the time teak has been used as alternative household assets for future income. Taufik (2001) stated that the central government has initiated reforestation program in 1980 and this may also have influenced the development of smallholder teak plantations in Gunungkidul area.

At present, smallholder teak plantation is dominating the forest cover in the area. Current total forest cover in the area has reached more than 42 thousands hectare or about 28.5 % of the total district land area. More than 29 thousands hectares (69%) of these forests are teak farm forests (Badan Pusat Statistik Kabupaten Gunungkidul, 2008). In general, teak is planted on almost all of land use system currently practiced by farmers. The

¹ Some of the senior farmers were interviewed at the beginning of the project implementation to collect information related with the history of smallholder teak plantations in the project sites. Informants included Bapak Somo Jamin at Katongan village and Bapak Wirorejo at Kedungkeris village.

types of smallholder teak plantation could be found in the form of *kitren*², *tegalan*³, *pekarangan*⁴ or home garden or as border planting on *sawah*⁵ or paddy fields (see Figure 3 for the illustrations). More detail explanation of this teak based farming system is discussed in the next section.

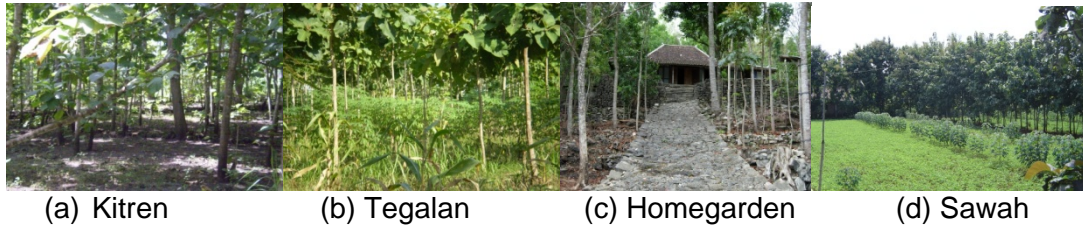


Figure 3. Different systems of smallholder teak plantations at Gunungkidul District

Teak farms in household economic structure

Teak has an important role in household economic structure, at least for some people such as the teak growers in Java, Indonesia. Regardless of their limited land ownership, teak growers in Gunungkidul District of Yogyakarta allocate about 10% of their land for *kitren* or teak woodlots (see Figure 4). Even on family with very limited land ownership (less than 0.5 ha), they still allocate around 9% of their land for teak woodlots. This phenomenon indicates that teak plantation had become an important option in household land use allocation system.

As stated earlier, teak in Gunungkidul District is planted in almost all types of land uses (*kitren*, *tegalan*, *pekarangan* and *sawah*). The results of farm inventory on 225 parcels of farmer's land showed that tree density ranged from 138 to 1,532 trees per hectare (see Table 1), where the majority (more than 75%) of the planted trees were teak.

² Kitren is a rain fed smallholder woodlot system where the main objective is teak production. Agriculture crops may also be cultivated during the earlier stage of teak plantation.

³ Tegalan is a rain fed farming system that produces both teak and agriculture crops. In this system teak is planted in an agroforestry system.

⁴ Home garden is a land use system adjacent to farmers' houses. In this system also teak is generally interplanted with agricultural crops or other tree species, such as fruits.

⁵ Sawah is an irrigated rice production system. Teak is commonly planted along the borders with at wide spacing.

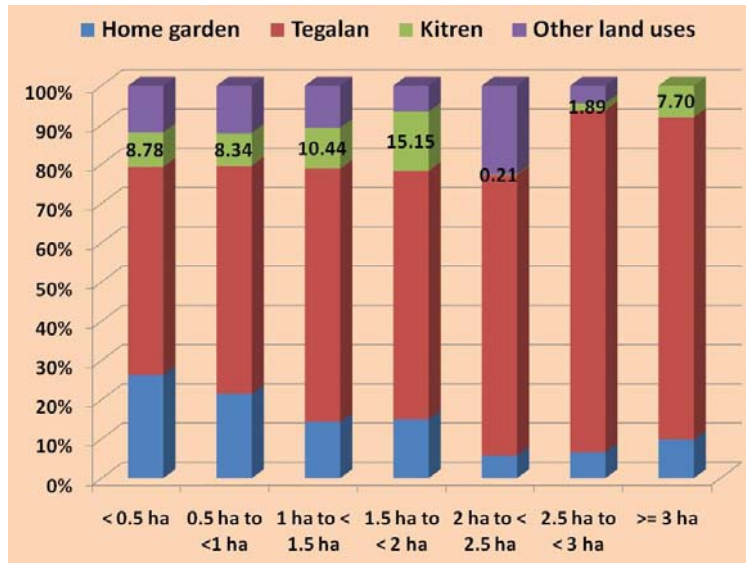


Figure 4. Land use allocation system by smallholder teak growers in Gunungkidul District, Yogyakarta

Table 1. Result of farm inventory on different smallholder land use system at Gunungkidul District, Yogyakarta.

Land use system	% from the total parcels measured	Average size of parcels (ha)	Average number of tree species planted	Average number of trees per ha
Tegalan	53.9	0.32	8	1,072
Pekarangan	23.8	0.16	13	1,177
Kitren	9.1	0.24	5	1,532
Sawah	8.5	0.24	7	138

The results of household surveys on 275 teak growers in Gunungkidul District, Yogyakarta revealed that the main reason by farmers on planting teak is for household savings accounts and source of cash for farmers during the emergency (see Figure 5). In urgent circumstances where farmers need cash, such as for family celebration or sending their children to a new school, farmers easily cut down and sell their teak trees (slash for cash). The other main reason is that planting teak has been regarded as part of their tradition or culture. Few teak growers (5%) who argued that their planting teak was driven by market (high demand and price) on teak.

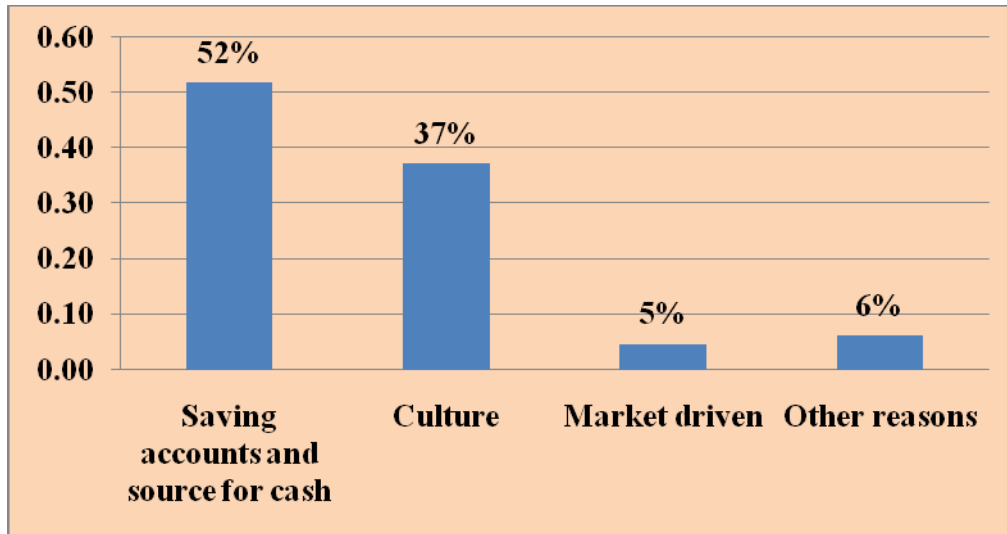


Figure 5. Reasons for planting teak by farmers (household survey results on 275 teak growers in Gunungkidul District, Yogyakarta)

From financial aspect, sales from teak share to about 12% of total household income (see Figure 6). When combined with other wood species, the contribution of timber plantation to household income is about 15%, still well below the share given by food crops and livestock (about 25%). The biggest share to household income comes from non-farm activities (61%), such as from labor works in the city, service providers or other informal sector activities. Although relatively low, the share of teak plantation in the household structure income is very important as part of diversification strategy of household income sources.

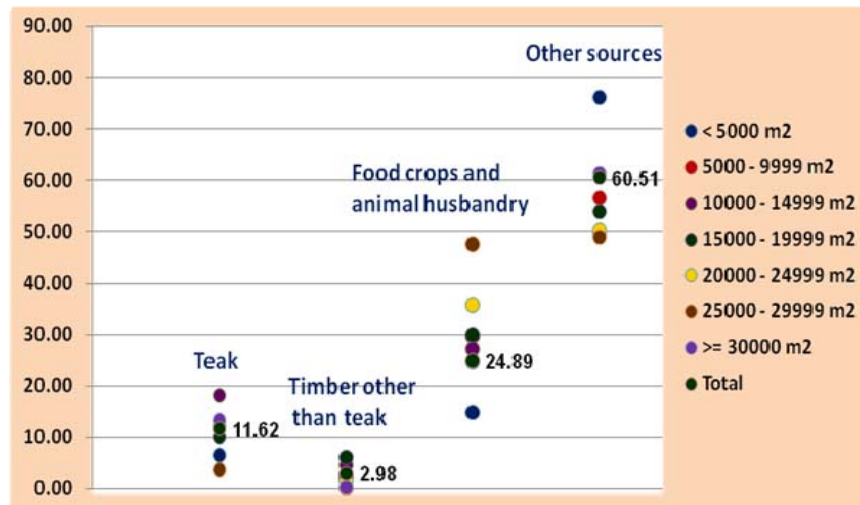


Figure 6. Share of teak sales in the household income structure at different size of land occupation (based on household survey of 275 teak growers in Gunungkidul District, Yogyakarta)

The lessons learned from the case of teak plantations in Gunungkidul, Yogyakarta concluded that planting teak could serve as a good strategy for household source of income. Teak plants play an important role as household saving accounts and can be cashed in easily in the case of emergency. The importance of teak for farmers was represented by farmers' land use system where teak always becomes an integral part in their farming system.

Challenges for improving economic outcomes for smallholder teak growers

The important role of teak plantation in the household economic structure has not yet been a sufficient motivating factor to farmers for more optimal investment on their teak plantations. So far smallholder teak plantation is generally seen as a source of additional income, although market opportunities of teak for both international and domestic are very high. There are various constraints faced by farmers to make teak plantations as a commercial business opportunity.

Although financially feasible, teak plantation provides only marginal benefits and relatively far below the benefits that can be earned from other farm commodities. In the case of Gunungkidul District, the financial benefits of teak plantation are still far below the benefits from growing food crops. Table 2 provides an illustration of these conditions. Table 2 shows that teak woodlot in the form of kitren produced benefit-cost ratio (BCR) of 2.35, which was generally smaller than the BCRs of tegalan or agroforestry systems. The Net Present Value (NPV) comparison between those systems shows that the tegalan system gives a much larger NPV than kitren system. The only advantage of kitren system is a relatively low establishment cost as compared to tegalan which is mainly dedicated for growing food crops.

The low financial benefits of teak plantation were caused by various factors in the production and marketing systems of smallholder teak. In the production systems, farmers generally apply traditional silvicultural practices. Most farmers still rely on local or naturally regenerated teak seedlings with low productivity. Fertilizers generally do not apply in teak kitren system. Fertilizers were applied mainly for food crops, although teak trees under the tegalan system receive the positive impact. Farmers do not apply thinning as this was considered as loss. Pruning sometimes is done, but farmers do this rather for collecting fuelwood and leaving the branch stub that may evolve into wood knot defects (Roshetko and Manurung, 2009). The traditional silviculture practices tend to produce teak wood with low productivity and quality, so that the selling prices received by farmers were also low. Farmers put low investment on teak plantation as it has not yet been viewed as a commercial venture. This phenomenon also occurs in teak farms at various parts of the world, where the range of teak planting costs varied very large (between U.S. \$ 100 to U.S. \$ 1000 per ha.) due to differences in management objectives (Enters, 2000).

Table 2. Financial analysis of smallholder teak-based farming system (per ha).

No.	Types of plantation	Cost of establishment		Maintenance cost until the first harvest		Potential income per month		Net Present Value		B/C ratio
		million Rp	US\$	million Rp	US\$	million Rp	US\$	million Rp	US\$	
1	Kitren system	3.51	369	1.03	108	0.83	88	15.07	1,586	2.35
2	Tegalan system:									
	Respondent 1	1.67	176	1.58	166	0.44	47	44.62	4,697	4.31
	Respondent 2	14.71	1,549	14.59	1,536	0.73	76	73.05	7,690	1.59
	Respondent 3	5.14	541	4.99	525	2.18	230	220.43	23,203	6.21
	Respondent 4	23.68	2,493	23.53	2,477	4.89	515	494.07	52,008	3.49
	Respondent 5	7.97	839	7.87	828	1.45	153	185.40	19,516	3.20

Limited knowledge of farmers on good silvicultural practices of teak was one among the limiting factors. The concept of silviculture in timber plantation were not yet familiarized by farmers. In kitren system, for example, farmers tend to plant teak at a very high tree density, slowing down the growth on tree diameter. Thinning is considered loss and farmers only fell the trees when the trees can be sold. Therefore, farmers often choose teak trees with large diameter in doing thinning. They are more precisely applying priming rather than thinning.

The traditional silvicultural practices were also caused by lack of farmer's capital in providing the production cost. Farmers in general are poor and they often at the condition of financial deficiency. In those situations, every available cash is prioritized to fulfil their daily needs or for investing in more productive activities, such as growing the food crops. Farmers' access to loans to finance intensive teak management was limited. Formal financial institutions such as government and private banks reluctant to provide loan for smallholder timber plantation business. The business was considered to have high risk because of long-term investment and limited collaterals owned by farmers (Nuryartono *et al.*, 2011). Limited access of farmers to loans often also force farmers to prematurely harvest their teak when they face with emergency situation with urgent need for cash. The practice reduces farmers' futures opportunity to gain more profit by selling larger diameter teak trees (Rohadi *et al.*, 2011).

In the marketing system, farmers generally sell their teak to middlemen. The middlemen estimates the price of trees by measuring their girth and their merchantable height. Basically, there is no standardized sale price for standing teak trees. When the price is offered, farmers will negotiate until an agreed price is set. Farmers generally have a lower bargaining position, because in the end they tend to accept the price as offered by the middlemen. This marketing system incurs some risks for both farmers and the middlemen. Farmers may be disadvantaged due to under valuation of the trees, but the middlemen could also have high risk due to severe defects of wood, such as hollow stems, which are invisible until the tree has been cut down. In addition, the middlemen have to pay the marketing costs that comprise the harvesting and transportation costs, as well as the transaction costs to obtain timber transport document (certificate of timber legality) from the District Forestry Office.

Strategy options for improving the economic benefits of teak farms

Teak farms business has considerable opportunities as means for rural economic development, in particular for improving farmer's income. However, the potential would not optimally be realized until the business is improved and teak plantations become more commercial venture. The case of smallholder teak plantations in Gunungkidul District, Yogyakarta gave some useful lessons for improving the role of teak plantations in the household economic structure.

One way that can directly improve the economic benefits of teak farms for farmers is by improving the productivity and quality of teak produced. Farmers need to encourage to use better quality of seeds or seedlings and apply better silviculture practices. For example, farmers need to apply thinning on teak stands up to the optimal amount (about 625 trees /ha at age of 4 to 6 years), apply pruning up to 60% of the total tree height and do not leave branch stubs, and maintain coppice by letting only the most healthy stem. Farmers' understanding of the benefits and practices of good silviculture needs to be taught by trained personnel (the forestry extension staffs) under community development programs, either supported by governments or non government organizations. It would be better if farmers' demonstration trials of managed teak stands are available to show farmers the effect of applying good silvicultural practices. These kind of plots often convince farmers to adopt and try on their own lands. The existence of guidance books on teak cultivation techniques with straightforward and easy language will greatly assist this effort.

Limited capital is one among the obstacles faced by farmers in optimal investment on their teak plantations. Farmer's access to capital need to be improved, such as by developing micro-credit institutions. Micro-credit institutions could increase farmer's access to capital requirements through easy and simple procedures (Nuryartono, 2011). These micro-credit institutions could be built by strengthening the capacity of existing community's finance institutions, such as the Rotating Savings and Credit Associations (ROSCA). Start with institutional strengthening of ROSCA, farmers' access to capital can be improved further through cooperation between ROSCA institutions and formal financial institutions such as commercial banks. These institutional strengthening requires intensive technical assistance from the government or NGO institutions. The support need to be focused on building leadership and effective control mechanism on organization by the members. The ROSCA institution should be able to provide services of relevant needs of farmers that may cover both financial and nonfinancial needs.

Improving marketing strategies of teak growers is an important element in the efforts to increase economic benefits of teak plantation business to farmers. Farmers and middlemen need to be introduced with teak log grading and pricing system applied by teak industries. This knowledge will help farmers to be more sensitive to produce higher quality of teak wood on their farms. Technical assistance should be provided by government and NGO agencies to provide farmers and middlemen with up dated market information.

Further effort, it would be necessary to develop business cooperation between the wood processing industries with teak farmer groups. This collaboration could open up a better market access for farmers and opportunities to engage in producing value added products. There are already some examples of such cooperation in Gunungkidul District.

Several groups of farmers cooperate with teak furniture manufacturer to produce certified teak furniture and applying the Forestry Stewardship Council (FSC) scheme. In this cooperation, the government could act to facilitate dialogue between the industries and farmers' groups and provide assistance to farmers' groups in preparing the contracts. This kind of cooperation may improve the opportunities of teak growers to connect with the global market, and thus opening wider market access for farmers (Nair, 2007).

On the regulatory aspect, we suggest to the government to simplify timber transport regulations to reduce transaction costs in teak marketing. Although the transaction costs are incurred to middlemen, as a consequence they transferred in the form of lower farm gate price received by teak growers. Simple and cheap procedures in assuring the legality of smallholder teak is incentives for the development of teak farm business.

Conclusions

Teak farms have high potential as means for improving rural livelihood. Teak farms provide employment opportunities as source of household income for farmers and significantly contribute to teak industries. Teak farms and teak processing industries provide employment for millions of people and contribute to economic development. These roles of teak farms are happening at some parts of the worlds as are being shown in Java, Indonesia.

The roles of teak farms in rural economy could be improved by improving the commercial values of teak farms to farmers. As illustrated by the case in Gunungkidul District, Indonesia, current teak farm business are limited to household saving accounts and farming culture, but has not yet develop into an optimal commercial venture. Teak growers are facing some obstacles in their efforts to gain more economic benefits from their teak farms. Some strategies need to be done to increase the economic benefits for farmers from planting teak activities and these may include:

- Increase knowledge and understanding of farmers for the benefit of applying proper silvicultural techniques. Government agencies or other community empowerment institutions need to support farmers through intensive extension program.
- Increase farmers' access to loans with quick and simple procedures. This effort could be done through the development of micro-credit institutions at village level.
- Improve marketing strategies of teak by farmers. This requires the improvement of market information systems so that farmers and middlemen could be more responsive to the standards of quality and prices that received and offered by teak industries. Farmers' groups need some assistances to build closer cooperation with teak wood industries. The collaboration could secure teak marketing channel by farmers and provides farmers with opportunities to engage in simple wood processing that adds the value of their teak wood.
- Government should revoke or revise regulations that may cause high transaction costs in teak marketing. In particular example, government should abolish or simplify current timber transport regulations to reduce transaction costs in teak marketing applied to middlemen and increase motivation of farmers to invest on more commercial teak plantations business.

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Deliberations

Technical Session I: Policy and legal framework

Dr. Markku Kanninen introduced the speaker Dr. Appanah and invited him to make the presentation. There was only one technical presentation. Dr. S. Appanah, spoke on 'Supportive policies and legal framework for growing teak'. He made a brief account of policies and legislation frameworks, their importance, its current standing and the need of the hour. He further explained the policy process as an *interactive process* that finally leads to further adjustments, renewal or reconfirmation taking examples from Thailand and State of Kerala, India. The highlight of the talk was on whether the existing policies and laws were in tandem with societal needs and that it is time to revisit the existing policy and legal dictum.

Subsequent to the presentation there were queries and discussion on diverse aspects of policies and related aspects. To a question on the components of political will, the speaker replied that political and economic will are closely related. Forestry has a low profile in less developed areas and hence the sector gets little political support. The situation in developed countries is the opposite. Complexity in political will and funding is another key area of concern.

With regard to the background that led to the work in Thailand and the reasons for comparison with Kerala situation, the speaker mentioned that it was because of the realisation that things have changed drastically in Thailand and the Government had approached FAO for assessing the scenario. The reason for comparison with Kerala was because the situation with regard to policies and laws of the Kerala Government are very people-oriented.

With regard to certification, Dr. Appanah replied that, besides policy and laws, certification is the key to forest governance to a large extent.

The audience was also interested to know the speaker's stand on climate change in relation to agroforestry and farm forestry. The answer was that climate change is all about money/credits. It certainly does not ensure money to people at large. Benefits are much more than carbon credits. Focus must be on the non-market benefits. Carbon is only an 'add-on'.

In response to a question on how the short-term policy framework support the long-term sustainability of plantation forestry, the speaker stated the need for revisiting the policy to implementation to the current situation. Many of the existing policies and laws are not in tandem with the changing short-term and long-term societal needs.

The session finally focussed on the future scenario of policy and legal frameworks for growing teak. It highlighted the need to understand the ever changing policy landscape, ever increasing /different demands on forests, the institutional reinventions, changing roles for forestry professionals, new skills, new knowledge, new challenges and the drivers of the change exercise. The session concluded with the emphasis on the need to revisit the very premise of the policy and legal framework and make the necessary interventions as and when required to suit the short and long term societal needs.

Technical Session II: Tree Improvement and Mass propagation

At the start of the session, the chairperson, Dr. Palanisamy gave an overview of the theme and introduced the speakers. Dr. Hansen was the first to speak; he made a detailed presentation on 'Choice of quality planting material for teak, a question of genetic business plan'.

It was noted by the participants that flowering time of different provenances brought together in a plantation can vary and whether there was any solution for this. Dr. Hansen admitted that as of now, no solution exists and it remains as a problem to be solved.

To a question on the difference in basal area of the clones in managed/unmanaged plantations, Dr. Hansen indicated them to be not much different.

It was noted that in many cases, when clones from reproductively isolated areas are brought together in a seed orchard, synchrony of flowering is upset resulting in low seed productivity. A solution was sought in this case since the investments are very high for raising seed orchards. The answer provided by the chairman of the session was to first select the best site for seed production and secondly restrict the selection of genotypes to the same agro climatic zone. There is also a need to provide ideal spacing (10 X 10m), i.e., only 80-100 trees/ha for increasing seed production.

A question was whether any of the forms of vegetative propagation can be practiced for establishing seed orchards. It was suggested that only bud grafting is practiced for clonal seed orchards. The audience was further interested to know how the clonal seed orchards could be so straight if bud grafting was followed. The speaker answered that sometimes there will be sprouting from stock and if it is not pruned at the proper time, it will overgrow scion and thus will be very straight in appearance. Molecular markers can be used to confirm whether the grown tree is a sprout of scion or stock.

In view of the problems for getting genetic material across countries, the participants were interested to know if TEAKNET could do something for exchange of materials. However, the difficulty in exchange of genetic materials across countries under the current laws was explained; in addition, the existing scarcity of seeds for domestic use within the country was also highlighted.

The next presentation by Dr. Shuchishweta V. Kendurkar on 'Micropropagation – an effective tool for mass propagation of quality planting stock of teak' touched upon the mass propagation techniques developed at NCL. The presentation aroused much interest and the following queries and answers came up during the discussion that followed.

With regard to the cost of one propagule, the speaker replied that it worked out below Rs. 10 and the private companies should come forward to get the know-how to reduce their cost from the current rate of Rs. 85.

The next query was about the genetic fidelity of the NCL clones that were referred to. The speaker answered that the clones were collected from Forest Department and the passport data of the collected clones are available. It is possible to micropropagate superior clones in large numbers, the progeny maintains high genetic fidelity and the NCL field trial data for more than 12 years with wood density analysis validates the

technology. Dr. Bhanja noted that the selection of clones should actually be based on multi-location field trials and the best performing clones should be selected for micro propagation through tissue culture.

It was observed that during the first 3-4 years, tissue culture plantlets grew fast and after that the growth slowed down. Branching was also more (12-13) in later multiplication trials and further somatic variations. Dr. Kendurkar said that if one is using minimal media there will not be any problem up to 90 cycles.

With regard to certification of tissue-culture-raised plants from seedlings, Dr. Kendurkar replied that different institutes followed different protocols. A consensus should come up among the institutes who are engaged in micropropagation activities. Dr. Bhanja noted that initial growth in first few years is due to juvenile vigour irrespective of tissue culture technique. After 20 years, if the original selection of clones is not authentic, there will only be 10-20% of heartwood, which is unacceptable to people.

Technical Session III: Plantation management

The session started with the introductory remarks of the chair, Dr. Manoranjan Bhanja. The first presentation was made by Dr. B. Mohan Kumar on 'Soil management in teak plantations'. Chemical and biological fertilization were suggested as remedies to resolve the crisis of site deterioration in forest plantations. However, there have been very few studies on nutrition aspects of teak plantations. A limited number of replacement series studies conducted by his team indicated that N-fixing trees improved growth of associated teak and enhanced soil nutrient concentrations. The discussions that followed helped to develop the concept that site quality and drainage were as important as nutrient status in determining productivity of teak plantations. A comparison of higher productivity of teak plantations in Costa Rica over Indonesia was discussed and it was explained that non-conventional teak growing areas were intensively managed and hence showed higher productivity than conventional regions. The general consensus was that a holistic approach was required for better management of teak plantations especially when it comes to seed production.

The second presentation was by Dr. Juha Lappi on 'Forest – level management planning'. He discussed a simulation – optimization approach for forest level management. The discussion was based on the JLP and J software developed by the author. In order to execute his programmes, the first requirement was the data for several treatment units/stands. For each of these treatment units, a number of treatment schedules for a given planning period consisting of several sub periods will be generated using a simulator. A linear programming problem setting can be used to select the optimal treatment combination. The discussion that followed agreed that Dr. Lappi's J software is commendable and based on the required datasets it can help in efficient forest management.

The third presentation in the session was by Dr. V.V. Sudheendrakumar on 'Health and sustainable management of teak stands'. He dealt with the various types of insect pests in teak plantations. The commendable achievements made by KFRI in the development of an NPV formulation against teak defoliator were outlined. The viral formulation assumes importance as control of the defoliator with other natural enemies is often difficult due to the highly migratory nature of *Hyblaea puera*. The major diseases that affect teak plantations were also dealt with. The discussions that followed saw Dr.

Sudheendrakumar explaining the mode, time and cost of application of the formulation HpNPV. He also explained that cytotoxic effects of formulated HpNPV were tested and no deleterious effects were found. The technical session ended with the concluding remarks by the chairman, Dr. Bhanja.

Technical Session IV: Wood utilization

The presentation by Dr. R.V. Rao on 'Innovative approaches in utilization of teak wood' focused on the uniqueness of teak wood as well as the new and innovative approaches in the usage of teak wood with several examples. The virtue of teak wood and the shortage of teak wood even for the purposes mentioned earlier restrict creation of any innovative new solid wood product out of teak wood. However, a lot of innovations are seen in product development in furniture, household items and artefacts. Certain other products which are in current use include like yacht flooring, bathroom roller, wooden mats, temple models, outdoor furniture items and handicraft items. It was also found that teak saw dust can be used as a precursor of an effective activated carbon under physical activation having microporous and mesoporous structure (pore size 0.6-100 nm). This can be employed as an adsorbent for dye removal from synthetic effluents.

The presentation also touched upon the quality of juvenile wood, smaller proportion of heartwood in short rotation teak and treatment of sapwood. The speaker pointed out the need for research to look into these aspects so that the status that teak enjoys amongst world timbers is maintained. In addition, logos specifying plantation /natural grown teak from specific country /region of origin on products was suggested.

Comparison of teak wood (for quality) from different countries so as to evolve International Grading Rules / Standards for teak was suggested by one participant. The TEAKNET coordinator mentioned about the initiatives in these lines taken by various agencies subsequent to a previous workshop at KFRI.

The question of any existing standards to identify and quantify juvenile/mature wood in planted teak was raised by one participant. The need to develop one was pointed out by the participant.

Session on Group interaction/Experience sharing - Problems and prospects of teak growing and trade

Dr. Appanah described the objective of the session and invited comments from the participants. The discussion is narrated here in two sub-sessions.

Teak cultivation

Mr. Hugh Brown and Ms. Valerie Fumey Nassah narrated some of the local problems they faced in Ghana in growing teak. The main problems were related to the early branching and flowering observed in teak. Dr. Palanasamy opined that this probably can be rectified by accommodating more trees per ha and minimising the spacing between trees. Trees grown in closer spacing develop straight boles and tend to prolong flowering. The fact was that, in Ghana, taungya cultivation was practiced in teak plantations which required wider spacing in teak plantations.

This was followed by a briefing on the practice of teak cultivation in Ghana by the delegates from Ghana. The spacing followed is 3 m X 3 m accommodating about 1111 seedlings per ha and taungya cultivation is very popular. First thinning is at the 8th or 10th year, during which half of the crop gets removed and the returns considered as income. The second thinning was at the 15th year bringing down the number to 200 trees per ha. Final felling is at the 25th year when around 150 trees per ha will be available. An average yield of 0.4 m³/tree is expected with a mean dbh of 25cm, giving rise to yield of 60 m³/ha. After the final felling a coppice crop is allowed. Discussion followed on coppice crop management. Dr. Manoranjan Bhanja opined that the optimum spacing that can be given in teak plantation is 2 m X 2 m.

Teak trade

Mr Richard John Laity opined that knowing the origin of the teak plantations in Australia is very difficult and they are not very sure about the seed source. He wanted a solution for this problem and how TEAKNET will be able to help them. He also suggested that it is high time we have a universal grading rule for teak. For this also he sought the assistance from TEAKNET.

Eco-labelling, barcoding and such other modern innovative techniques were suggested to be resorted to for the identification problem. With regard to the grading rules, it was suggested that a restructuring of the grading rules for planted teak would have to be done. The reply given was that TEAKNET would not be able to implement uniform log grading rules. Consultants will have to be engaged to examine the existing rules and recommend a mutually agreeable set of grades. TEAKNET at this stage shall be able to bring out the issue for discussion in its Cost Rica meeting.

Detailed discussions were conducted with regard to certification of planted teak forests and the opinion was that there is tremendous potential for certification and, in fact, it was presumed that the timber from a certified plantation will fetch an enhanced income of 30 percent.

Technical Session V: Climate change and social dimension

Dr. Jose Kallarackal made opening remarks on the role of forests in the climate change mitigation through carbon sequestration and regulation of green house effect and invited Dr. Markku Kanninen for making presentation, on 'Teak plantations for climate change mitigation and ecological services'.

Dr. Markku Kanninen redefined the scope of his presentation to a wider topical area of 'Climate change mitigation and ecosystem services'. The speaker proceeded by clarifying the concepts such as ecosystem services and set of factors fuelling climate change including demand for fuel, landscape fragmentation and degradation of natural and man-made ecosystems. Ecosystem services were explained at local, global, and landscape levels. Further, the link between ecosystem services and well-being was elaborated especially the kinds of services such as provisioning, regulating services and cultural services. To illustrate the possibility of monetizing of the Ecosystem Services and refinancing it for promoting local climate change mitigation measures, the case of 'payments for ecosystem services' in Costa Rica was quoted and elaborated. Vulnerability of ecosystem services was explained. Further, the ecosystem services from plantations were highlighted and this was linked to the concepts of REDD+. Carbon

sequestration pattern in unmanaged, selection felling, long-rotation and shorter rotation systems was elaborated. The CO₂ FIX MODEL was explained in detail and further the issues relating to biodiversity management in plantations, trade-offs between management options were considered. With this, the floor was opened for discussion by the chair.

Issues such as poor availability of carbon sequestration values and possibility of circumventing the situation by snowballing with whatever available data were explained as an initial strategy. The suitability and replicability of the Costa Rican model for other localities was doubted by some of the participants.

The second presentation by Mr. Dede Rohadi was on the 'Teak Farms- a strategy for growth and job creation in Rural Asia'. The speaker described the origins of the small holder teak farms in Indonesia and their importance in the local economy. Result of an ACIAR funded study indicating the patterns, holding size and drivers of planting were presented. According to the study, 52 percent of the households planted teak as a source of cash, 37 percent considered planting for the tradition. However, the yield and quality of the plantation remained very low in the absence of adoption of proper silvicultural technique, lack of access to the financial aids and overall indifference of the cultivators to the long-term planning. The presentation concluded with a statement that teak farms have potential for rural poverty alleviation but in the absence of better incentive structures, this goal is far from achieved. To tackle this, a four pronged strategy including technical assistance, formation of micro-credit organisations, developing market intelligence and simplification of government stipulations were recommended.

Feedback Session

Dr. Appanah invited suggestions on improving the state of affairs with respect to teak at the global level and also with respect to the deliberations of the programme just held.

Mr Hugh Brown enquired if exchange of seeds could be arranged by TEAKNET. It was made clear that TEAKNET as an organization is not equipped to perform such tasks but ways by which this can be facilitated can be investigated.

Mr. Richard Laity suggested that information on regulations regarding the export/import of teak wood needs to be made available to the growers and traders. Dr. Jayaraman agreed to compile this information. Mr. Laity also indicated that the teak traders could be benefited by information on price of teak. Dr. Jayaraman described the facility for TEAKNET members to advertise their products in the TEAKNET website and also the market intelligence system being executed by TEAKNET.

Dr. Bhanja suggested that success stories with teak can be shared amongst the growers. Dr. Markku Kanninen noted that failure stories are equally important as we can learn from such experiences as well. Dr. Jayaraman indicated that *Teaknet Bulletin* could be an appropriate medium for publicizing such experiences.

Dr. Chand Basha indicated the need to publicize the information on research findings on teak on a regular basis. Dr. Jayaraman indicated the availability of regularly updated bibliography on teak in the TEAKNET website.

Dr. Palanisamy indicated the need to provide travel funds for participants to attend international conferences. Dr. Appanah pointed out that such things are possible when TEAKNET is able to generate enough funds, which requires support from different agencies through membership.

Dr. Anoop wanted climatic models to be developed based on dendrochronological data collected from different countries. Dr. Jayaraman indicated that such ideas are to be pursued in the form of regular project proposals by the concerned. Dr. Appanah noted that TEAKNET shall be able to bring out such issues to the limelight but the research will have to be carried out by the institutions involved.

Mr. Rajesh enquired if TEAKNET could do something to arrest the deteriorating productivity of teak plantations in Kerala. Dr. Bhanja said, it is an internal management problem of the Forest Department and needs to be resolved at that level itself.

Mr. Rajesh also noted that all he could hear at the programme was some probability statements regarding soil management in teak plantations. Although no definitive replies were made at the moment, it was felt that Dr. Mohan Kumar who spoke on soil management had given certain clear indications on how to manage soils under teak plantations. Based on the trials by Kerala Agricultural University, he had recommended the use of subabul in teak plantations to enrich soil nitrogen and also recommended to avoid slash burning during site preparation. Regarding absence of response to fertilizers by teak, he had forwarded a few hypotheses/ possible explanations on the phenomenon.

The participants in general felt the programme to be informative and useful.

Concluding Session

Dr. Appanah stressed on the need to strengthen the network so that fruitful interaction takes place between the stakeholders. Dr. Jayaraman proposed vote of thanks and the workshop ended with the announcements for the next days' programme.

Major issues/observations brought out through the training workshop

- Forest policies have to be in tandem with societal needs. Besides forest policy and laws, certification has a key role to play in forest governance. Works on climate change put much emphasis on money and credits. The benefits are much more than carbon credits and hence the focus must be on the non-market benefits.
- Non-synchrony of flowering of trees in seed orchards results in low seed production which is a serious problem to be addressed. Restricting the selection of genotypes for raising seed orchards to a common agro-climatic zone and the use of ideal spacing (80-100 trees/ha) have been recommended to avoid the problem.
- Closer spacing was suggested to avoid early branching and flowering of teak trees in plantations in Ghana.

- A question was whether TEAKNET could facilitate exchange of genetic material across countries. TEAKNET could facilitate the process but cannot get directly involved.
- Selection of superior genotypes is a very important issue to be considered before undertaking their mass-propagation.
- Growing N-fixing trees in teak plantations and avoiding slash burning during site preparation are beneficial to the growth of teak trees.
- The productivity of teak in non-traditional areas has been found to be higher due to better management.
- Forest-level management planning based on quantitative techniques is helpful in optimizing the management of resources.
- Control of defoliator pest in teak is achievable through the use of viral formulation developed by KFRI.
- Teak is one of the most virtuous woods available for a multitude of uses ranging from making of buildings, furniture, ships/yachts, handicrafts and even its sawdust being used for production of activated carbon which has applications as an adsorbent for dye removal from synthetic effluents.
- Research is needed to explore to what extent, the sapwood of juvenile wood or heartwood of juvenile wood show dimensional stability, resistance to termite attack and repellence to water and whether treated sapwood of teak would exhibit all the unique properties of heartwood of mature teak.
- Unification of log-grading rules needs to be addressed as an international issue.
- Factors fuelling climate change were delineated and ecosystem services offered by forests were explained. Issues such as poor availability of carbon sequestration values were highlighted.
- The Indonesian experience revealed that teak farms have a potential to alleviate rural poverty but demonstrated that in the absence of better incentive structures, this goal is far from achieved. A four pronged strategy including technical assistance, formation of micro-credit organisations, developing market intelligence and simplification of government stipulations was recommended.

Presentations



Innovations in the Management of Planted Teak Forests

30 August 2011, KFRI, India



Supportive policies and legal frameworks for growing teak

Simmathiri Appanah
FAO Forestry Officer



Presentation

- **Introduction**
 - **What are policies and legislation frameworks?**
 - **Why are policies and laws important?**
 - **How are they mismatched with current needs?**
 - **What needs to be addressed?**
-

Introduction

A Thai Affair...



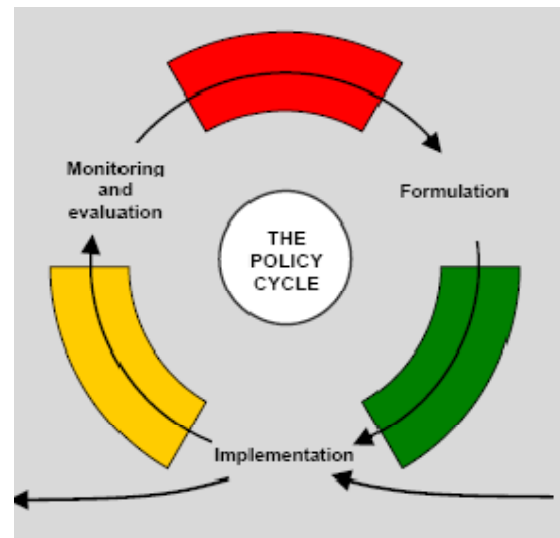
What are policies?

- Policies

- ✓ Definite course or method of action selected among alternatives and in light of given conditions to guide and determine present and future decisions
 - ✓ Articulation of courses of actions to achieve specific objectives
 - ✓ Forest policies are concerned with the manner in which forests and tree resources should be managed to meet society's demand for goods and services that forests can provide for present and future generations
-

Policy process

- Forest policy has content in the form of statements and instruments designed to achieve a desired objective
- It is an iterative process: formulation, implementation and review – the review leads to further adjustments, renewal or reconfirmation



What are legal frameworks/ legislations?

Legislation:

- The act or process of making laws (enactment) and the laws so made
 - Many purposes:
 - ✓ provides legal support for policy implementation
 - ✓ to regulate, authorize, provide funds, sanction, grant, declare, & restrict
 - ✓ basis for long-term framework for forest management, conservation
 - Other terms (bills, decrees, rules, regulations)
-

The Question:

Do existing policies and laws support forest plantations?

First, what are forest plantations?

- **Forest plantation stands:**

a) Established by planting or/and seeding in the process of afforestation or reforestation, either native or introduced species, with following criteria: one or two species at planting, even age class, regular spacing (FRA/FAO 2000);

b) Or intensively managed stands of indigenous species, with one or two species at planting, even age class, and regular spacing.

- **Manmade forests**

- **For discussion purposes** – plantations, farm forests, agroforests

Do existing policies and laws support forest plantations?

- Are the policies and laws in tandem with societal needs?
 - Let's review some policies and laws – e.g. Thailand
-

Do existing policies and laws support forest plantations?

- Thailand's Forest Policy of 1985 – Provisions for tree farming:
 - ❖ role and responsibility sharing among government agencies and private sector promoted
 - ❖ private and public sectors shall manage forests for providing benefits perpetually
 - ❖ community forestry, agroforestry and farm forestry shall be encouraged
 - ❖ state shall promote reforestation by the public and private sectors
 - ❖ incentive system shall be established to promote reforestation by the private sector
-

So, what is the problem?

- Scenario changed, 1985 policy outdated!
 - Forest cover shrunk to 28%, from 40% in 1985
 - Logging ban imposed in 1989
 - Millions of people occupying national forest reserves & protected areas
 - National Forest Act 1964 precedes Forest Policy of 1985
 - Reforestation by private sector not supported through legislation
 - Community Forestry bill could not be implemented
-

Let's look further into the problems

1) Change in scenario:

- Rapid shift in priorities in recent decades to conservation over production

2) 40 % forest cover unrealistic:

- No analysis undertaken
 - Needs of forest dwellers, migrants not considered
 - Real land use and land rights of people not addressed
 - Occupied lands were classified under forest areas to achieve 40% forest cover
 - Logging ban imposed in 1989
-

Let's look further into the problems

3) Logging ban in 1989:

- Knee jerk reaction to flash floods and loss of life
- No analysis – floods erroneously implicated to logging
- No review of timber needs – no policies to address deficits
- Industries suffered
- Illegal logging increased

4) Forest Policy of 1985 implemented through Forest Act 1964:

- Mismatch
 - Agriculture expanding through land reform and land code provisions
 - Illegal farming encouraged over forest plantations in degraded forest areas (ownership claims)
-

Deficiencies and weaknesses



- Outdated policies and legislation
 - Lack of broad stakeholder consultation
 - Imbalances in stakeholder power
 - Weak strategic planning capabilities
 - Weak implementation capacities
 - Weak political will
 - Absence of supporting legislation, strategies and operational plans
 - Attitudes of individuals and institutions
 - Overly prescriptive and bureaucratic environments
 - Forestry and climate change
-

What then are good policies for plantations – some guiding principles

- No top down approaches; inclusive and iterative processes
 - Meeting existing social, economic, environmental conditions
 - Stakeholder participation
 - Livelihoods focused, incentives raised
 - Commercial tree planting devolved (private sector...)
 - R&D support
 - Land/tenurial rights resolved, clear
-

Look at Reforestation Act (1992) & Forest Act (1985)

Too many restrictive regulatory provisions discourage farmers: i) farmer can grow and cut trees under Reforestation Act; ii) transport and sawmilling permit under Forest Act!

Activity	Act
Right to raise trees in private land	-Registration for reforestation, exploitation certificate, land code certificate
Reserved spp.	Permit for cutting
Royalties	Marking hammer registered
Hauling, transport	Must bear hammer mark
Lumber operation	Lawful acquisition

Kerala Promotion of Tree Growth in Non-Forest Areas Act (2005; amended 2007)

Activity	Act
Land rights to grow trees	- all private lands, lands vested to local governments - owner free to plant trees on land
Notified tree spp.	Sandal wood
Reserved tree spp. cutting and removal permit	Teak, rosewood, Xylia, Terminalia, Hopea
Scheduled tree species – no permit	Coconut, rubberwood, cashew, tamarind, mango, jack etc.

Kerala Promotion of Tree Growth in Non-Forest Areas Act (2005; amended 2007)

Activity	Act
Rights, permit to cut, removal, log, trade	owner of land in non-forest land has right to cut and transport any tree standing on his land, except sandalwood
Hauling, moving, transportation	Owner files to authorized officer a declaration
Duties of Forest Department	-develop, maintain nurseries, approve private nurseries - execute social forestry schemes - provide technical assistance
Duties of local government	- cultivate trees in lands vested - carry out census - maintain nurseries - organize extension services

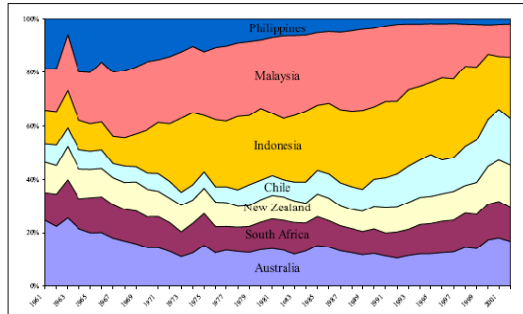
The future



- Change is the only constant
- Ever-changing policy landscape
- More and different demands on forests
- Institutional reinventions
- Changing roles for forestry professionals
- New skills, new knowledge, new challenges
- Drivers of change exercise



Why plantations?



Source: FAOSTAT (2004).

Figure 3: Comparative shares of wood production: Southeast Asian countries versus southern plantation countries

- Natural forest area shrinking
 - NF – less for timber production, more for biodiversity conservation, ecological services, etc.
 - Plantations (plantations, farm forestry, agroforestry) high prospects, practical, focus on high returns, livelihood, even conservation potential
 - Man-made forests, especially those in private lands, would achieve high potential for wood production
-



Tips and Template for Writing a Policy Brief

- **Characteristics of a Good Policy Brief:** persuasive, organized, brief

- **General Outline for a Policy Brief**

- Introduction:** Overview, Problem, Objective, State where you aim to go

- Recommendations:** State them upfront

- Background:** Brief relevant history

- Analysis:** Constructively criticize, use evidence

- Conclusion:** Persuasive argument & summary statement



Choice of quality planting material in Teak, a question of a 'genetic business plan'

Jon Kehlet Hansen, Lars Graudal, Bjerne Ditlevsen and Erik D. Kjaer



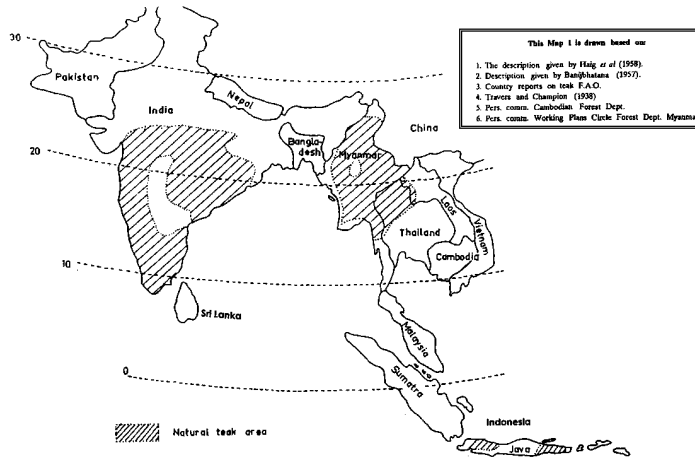
Outline

- Prerequisite to plant material
- Provenance variation
- Provenance-environment (seed source-environment) interactions
- Genetic variation between individual trees
- Domestication of teak: how to do in the light of seed source-environment interactions?
- Conclusion





Natural distribution area of teak



- Wide climatic range
 - Annual rainfall between 1000-2700 mm
 - Typically 3-5 month dry season
 - Landraces in more moist climates without dry season



Prerequisites to plant material

- Adapted to planting site
 - High survival
 - Superior growth
 - Resistance to pests and diseases
- High external wood quality
 - Stem straightness
 - Low buttress and fluting
 - Low frequency of forks
 - Low frequency of epicormics
- Internal wood quality





Prerequisite to plant material

Wood quality factors	Wood properties	Remarks
1. Mechanical factors	1a. Modulus of elasticity 1b. Modulus of rupture 1c. Maximum crushing strength 1d. Hardness (for flooring uses) 1e. Growth stresses	1a, 1b, 1c and 1d are correlated to specific gravity in the early stage of tree development. For young trees.
2. Physical factors	2a. Shrinkage 2b. Tangential / Radial shrinkage 2c. Sorption properties such as fiber saturation point	Assessed in the three different directions of wood structure. Anisotropic ratio indicating dimensional stability. Key impact on dimensional stability.
3. Biological factors	3a. Decay resistance 3b. Termite resistance 3c. Weather resistance	Reflect the natural durability.
4. Aesthetic factors	4a. Color and veining 4b. Grain 4c. Texture	Can be referred to under the same generic term of "figure".
5. Structural factors	5a. Heartwood / sapwood ratio 5b. Bole shape (straightness, taper, buttressing, fluting) 5c. Knots size and frequency 5d. Grain angle	Important for sawing as directly related to timber yield (i.e.: sawn timber grade and recovery).



Provenance variation

- **Adaptation and growth**
 - Huge differences in survival and growth
- **External stem quality**
 - Persistence of axis
 - Epicormics,
 - Protuberant buds
 - Buttressing
 - Stem form/straightness
 - Branch size
- **Wood quality**
 - Percentage heartwood
 - Fibre length, strength, specific gravity, shrinkage, durability, termite resistance, extractives from the wood, colour of heartwood





	Straightness score 4+5 (%)
Provenance	%-point
G1 (Ghana)	-5
G3 (Ghana)	-11
G4 (Ghana)	-13
Jemar (Ghana)	-12
Nilambur Kerala (India moist)	19
Bairluty 1, A.P. (India dry)	-5
Bangsri, Pati (Indonesia)	10
Nanas, Blora (Indonesia)	-2
Ngliron (Indonesia)	-3
Temandsang (Indonesia)	9
Vientiane Town (Laos)	8
Savannakhet I (Laos)	3
Savannakhet II (Laos)	2
Mean across sites	42
Max	19
Min	-13



Provenance by environmental interaction

- Genotype-environment interactions
 - Region by provenance-region interaction
 - Survival and growth
 - Health
 - Persistence of axis
 - Epicormics
 - Protuberant buds
 - Buttressing
 - Stem form/straightness
 - Branch size
 - Large variation within provenance regions



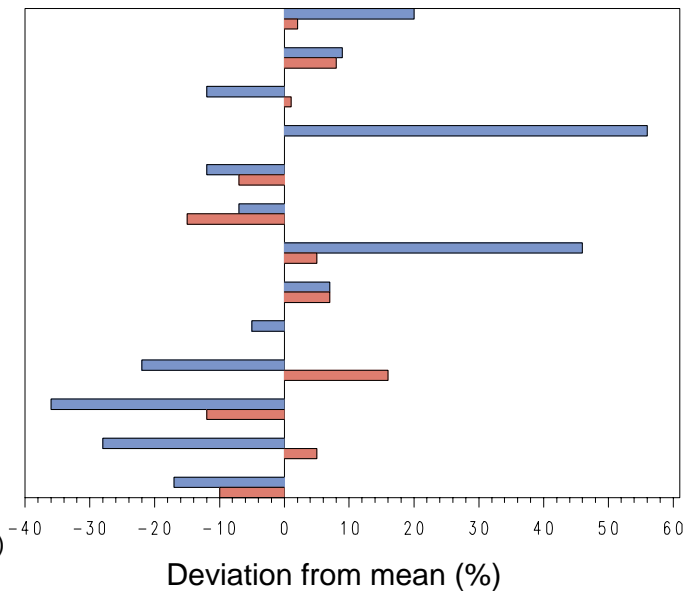


Provenance variation and provenance - environment interaction

Provenance

Basal area m²/plot (age 28)

- G1 (Ghana)
- G3 (Ghana)
- G4 (Ghana)
- Nilambur Kerala (India moist)
- Bairlutry 1, A.P. (India dry)
- Jemar (Ghana)
- Bangsri, Pati (Indonesia moist)
- Nanas, Blora (Indonesia)
- Ngliron (Indonesia dry)
- Temandsang (Indonesia dry)
- Savannakhet I (Laos)
- Savannakhet II (Laos)
- Vientiane Town (Laos)



Blue – Semi moist (annual rainfall 1600 mm)
Red – Dry (annual rainfall 1100 mm)

Deviation from mean (%)



Provenance by environmental interaction

Results from international field trials

- **Climatic match between provenance and planting site uncertain!**



Genetic variation between individual trees

- Growth (mainly young material < age 10 years)
 - Narrow sense heritability estimates range: 0.05-0.76
 - Based on open pollinated families
 - Broad sense heritability estimates: 0.28-0.37
 - Coefficient of variation: 14-19%
- Fork height
 - Narrow sense heritability of 0.56 (± 0.16)
- Stem straightness
 - Low to moderate narrow and broad sense heritability in young material
 - In 3.5-year-old trial (0.07 and 0.12, respectively)
 - In 12-year-old trial 0.23
 - However, strikingly straight clones observed in clonal seed orchards in Thailand and in demonstration plots with clones of selected trees from the Solomon Island landrace



Teak clones in Thai seed orchard based on selection in the 1960'ties. Very straight trees





Case: Sapwood – Heartwood

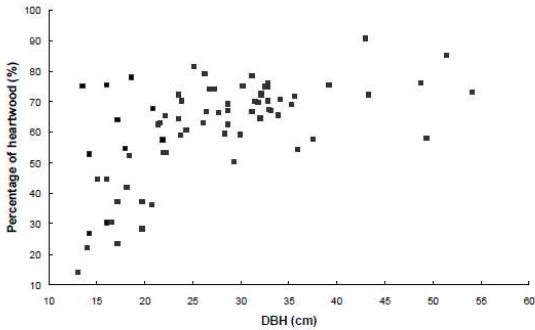
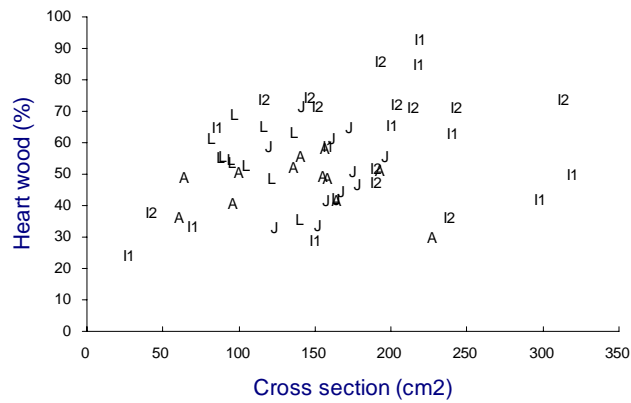


Fig. 4. Relationship between heartwood ratio and DBH of trees of various ages ($y = 40.12 \ln(x) - 71.44$, $R^2 = 0.61$).



Genetic variation between individual trees

- Heart wood percentage
 - Narrow sense heritability estimates of 0.69 and 0.80
 - Phenotypic standard deviation about 14% (diameter)
- Significant differences in forking, branching, bending, fluting and flowering
- Genetic correlations
 - Low for growth with external stem quality traits and heartwood percentage, with a tendency to negative correlation between growth and stem straightness
 - Growth and wood quality traits ?





Possible genetic gains

- Growth
 - Possibly genetic gains in the range 10-20% depending on selection intensity
- Stem straightness
 - Small to moderate ? Conflicting results
- Heart wood percentage
 - Large opportunities to increase heartwood percentage
- Wood quality traits?
- A two stage selection
 - 1. stage - selection for growth and external stem quality at age 10
 - 2. stage – selection for high heartwood percentage and wood quality using wood cores samples



Individual tree variation

Mass selection for heartwood percentage

	Before selection	After selection $i=1.755$ (10%)	After selection $i=1.755$ (10%)
Narrow sense heritability		0.70	0.53 *
Total diameter cm	16	16	16
Heart wood % mean	57	74	70
Heartwood diameter cm	9	12	11
Total ba cm ²	191	191	191
Heartwood ba cm ²	62	105	94
Heartwood % ba	32	55	49

*assumption that OP-families = half sibs does not fully hold.

(Based on Mandal and Chawhan, 2005)





Genetic business plan – why?

- The prediction of the performance of a certain provenance at a given planting site based on e.g. climate match is uncertain.
- The degree of seed source by environmental interaction is high
- The potential value of improving the applied planting material through selection is considerable



Domestication of teak: how to do?

- Setup of local tests to find the most suitable genetic material
- **Make immediate plantings genetically diverse to avoid total failure in short or long term**
 - E.g. examples from poplar breeding on failures due to poor genetic diversity – use of one clone





Domestication of teak: how to do?

- Setup of a multiple populations breeding system
 - Tests with seedlings from seed sources can serve as breeding seed orchards
 - Breeding seed orchards for different sites and purposes
- Obtain adaptive material and a high degree of genetic diversity in the breeding population
- Loss of rare, but potentially important alleles, is reduced



Setup of a multiple populations breeding system

- Extensive seedling seed orchards (SSO)
 - Larger plantings with different genetic material
 - Track of seed sources, but not families
 - Replications within SSOs to improve selections
 - Selective thinning based on phenotypic values, assumption about heritabilities and adjustment for seed source differences
 - Will provide knowledge on seed source-environment interaction
- Extensive seedling seed orchards
 - Mix of genetic material
 - No track of seed sources
 - Will not provide knowledge on seed source-environment interactions



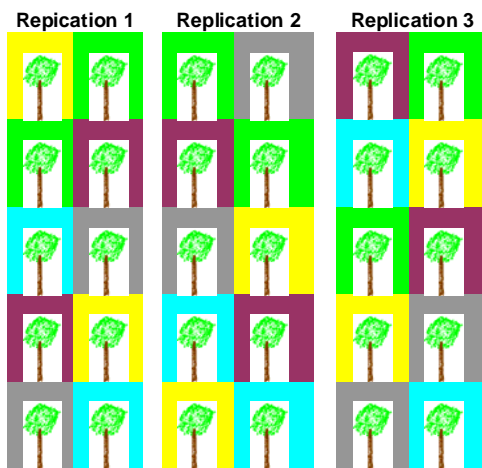


Setup of a multiple populations breeding system

- Intensively managed seed seedling orchards (SSO)
 - Track of seed sources and relationships in SSO (families, clones)
- Selective thinning based on estimated breeding values within and across sites
- Track of relationship makes it possible to control inbreeding
- Provide estimate of the degree of genotype-environment interaction at seed source and individual tree level

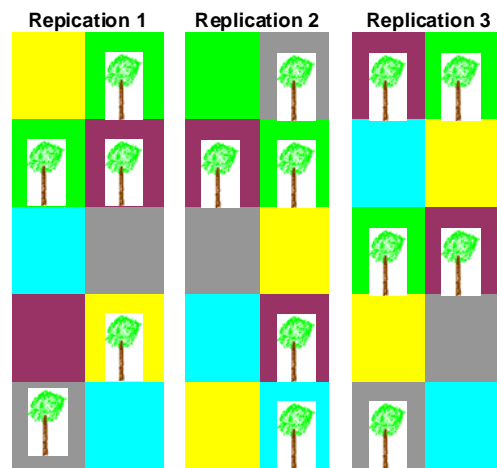


Year 0: Establishment of BSO



Year 10: 1. stage selection for growth and external stem quality. 2. stage selection for heartwood percentage and wood quality

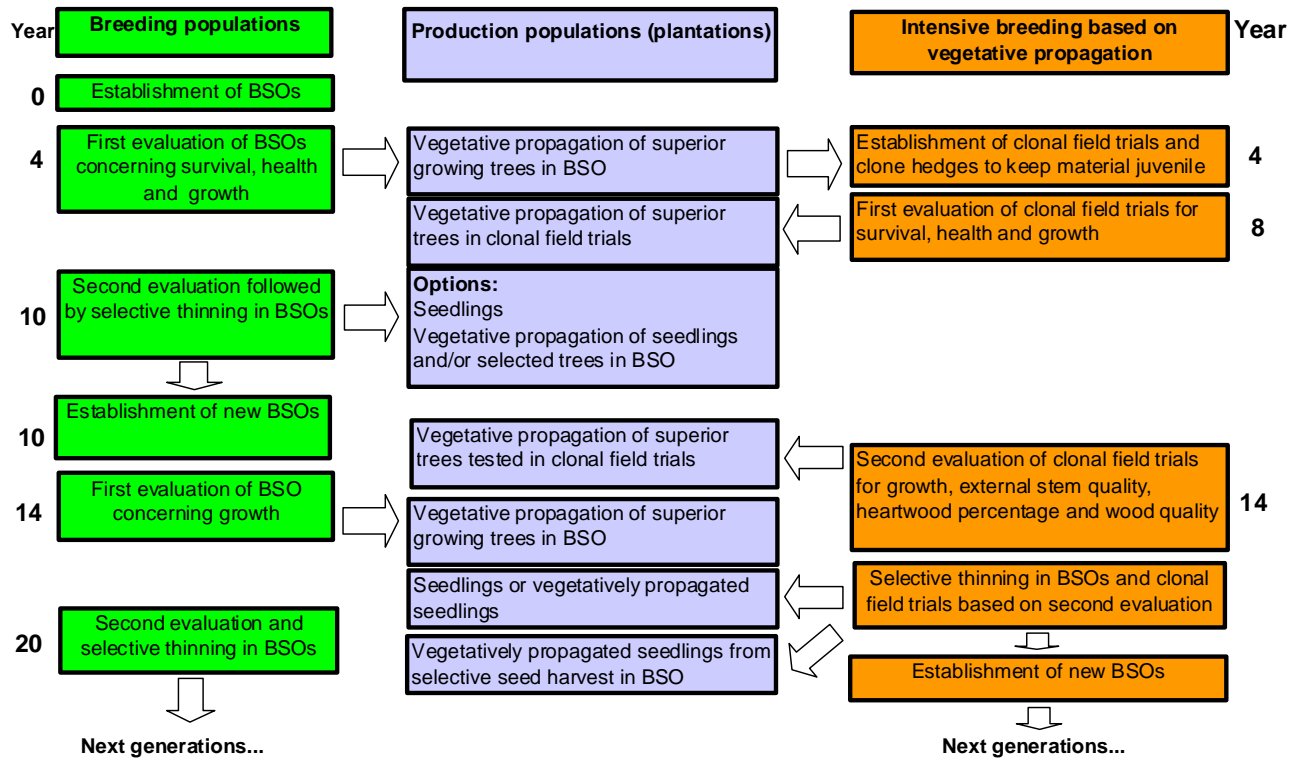
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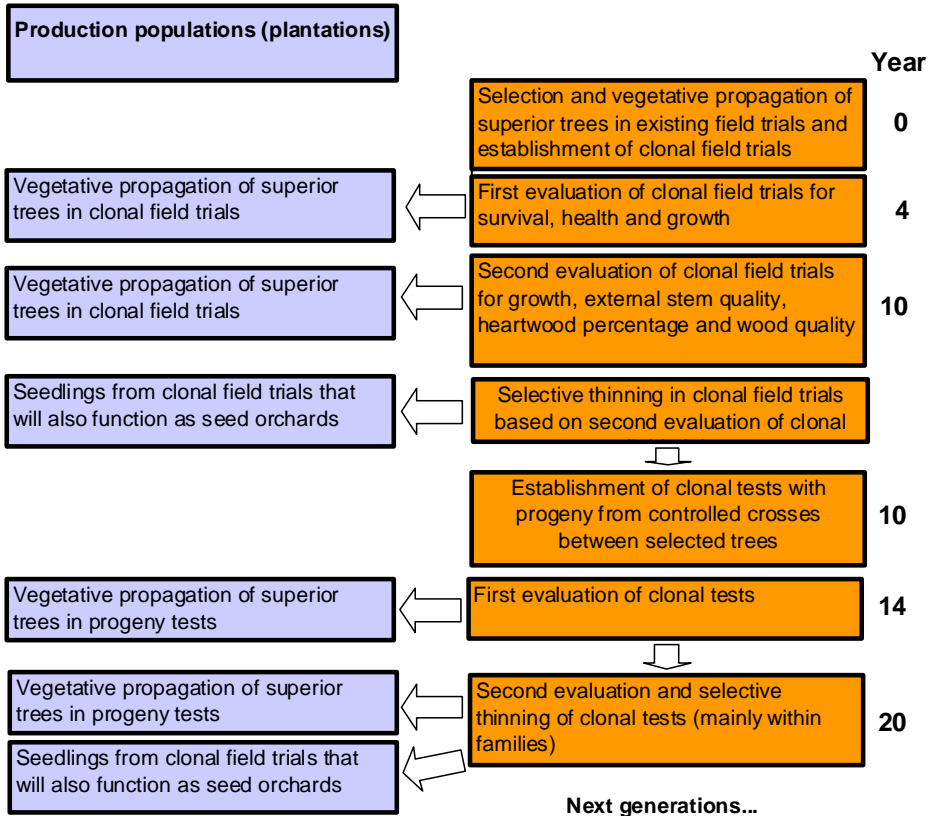
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etc.

Replications at each site and track of seed source makes it possible to identify the best performing seed source at each site and to estimate the degree of seed-source-environment interaction





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Genetic material for the breeding seed orchards (BSO)

- Exploit local landraces/provenances if they show good adaptation, growth and quality
- Identification and selection of seed sources from regions with similar ecological conditions as planting site
- Use information from field trial series to limit the number of seed sources of interest
- Exploit international provenance field trials
- Include tested and selected material e.g. seed from tested clones in seed orchards or tested clones



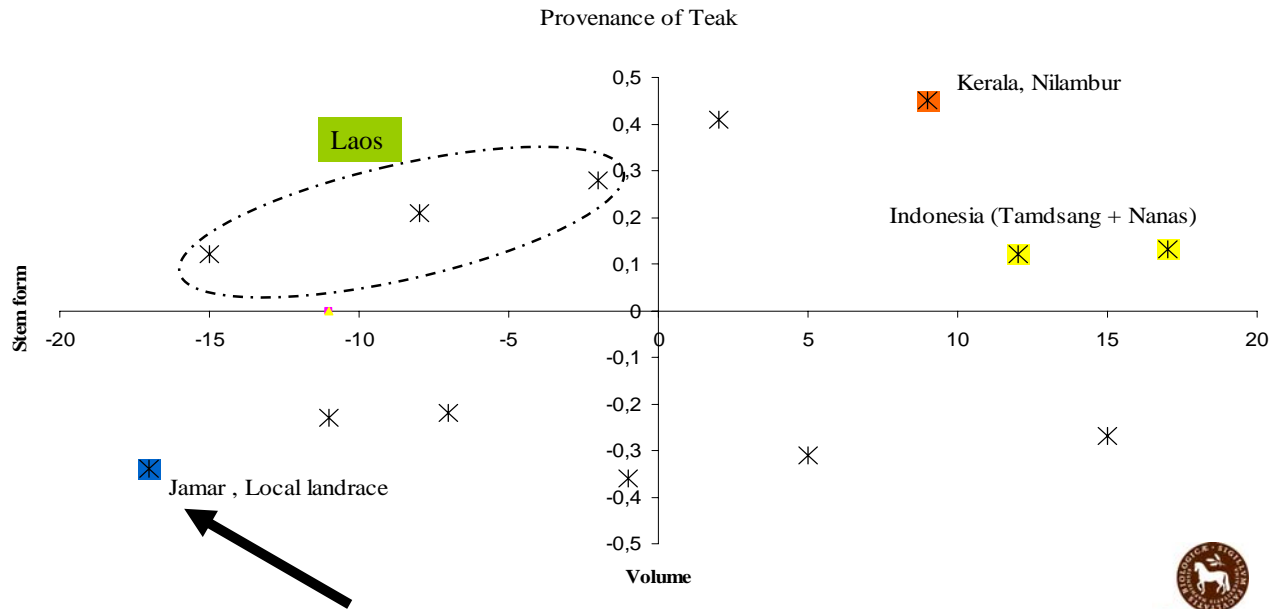
Landraces from Tanzania



11 year planting, Longuza, Tanzania



Landraces: may not be the best choice (example from Ghana)



From Ofori *et al* (2008)



Identification of potentially superior genetic material

- Early results from "All-India provenance trials"
 - Local provenances will likely perform best, but introductions from moist India may grow better
 - South West India (Nilambur) tended to prove more stable and vigorous.
 - Practical experiences is that Nilambur when planted in dry areas will often suffer from low survival, but that growth of surviving trees is good



Identification of potentially superior genetic material

- Indonesian series
 - Generally, it was possible to find Indonesian landraces with as much growth as the best exotics
 - Indonesian landraces of moderate external stem quality
 - Two Lao provenances proved superior concerning stem form and branching
 - An Indian Malabar provenance showed generally good growth, but was characterised by large number of branches



Identification of potentially superior genetic material

- Chinese series of provenance field trials
 - A south-West Indian provenance (Sungam, Kerala) produced 50% more volume than the best Burmese provenance and showed better drought resistance compared to Burmese and Thailand provenances in nursery field trials
- Provenance field trials in Thailand
 - Relative small variation between the Thailand provenances





Identification of potentially superior genetic material

- International DFSC coordinated series of field trials – age 9 and 17 years
 - Indonesian landraces prove generally good survival and growth (but with important exceptions). However, they are characterised by a tendency to big branches, more pronounced buttressing, higher frequency of epicormics and less straight stems (but again with exceptions).
 - Provenances from Kerala are generally characterised by good growth, high stem quality, fine branches, but might be inferior in health in the youth at some sites.
 - Outside Thailand, provenances from Thailand are among the slower growing and can be unpredictable regarding survival and health, but stem quality is generally good and branch size small.



Identification of potentially genetic material

- Two 28-year-old field trials in Ghana (Semi-moist and dry). Both trials part of the DFSC coordinated field trial series
 - Nilambur (Kerala) superior at both sites concerning stem straightness and low buttressing. Highly superior growth at the semi-moist site and moderate growth at dry site.





Identification of potentially superior genetic material

- One 28-year-old and one 32-year-old field trial in Ivory Coast (semi-moist sites)
 - Nilambur superior concerning growth, stem straightness, buttressing and epicormics
 - Masale Valley (South West Indian) superior growth, reasonable buttressing, but otherwise poor external stem quality.
 - Tanzanian landrace Kihuhwi superior concerning growth, but intermediary in external stem quality
- One 30-year-old field trial in Tanzania, semi-moist conditions
 - South Western Indian provenance Topslip highly superior growth and stem straightness



Identification of potentially superior genetic material

- Malaysia (moist conditions), age 106 months
 - Landraces of Solomon Island superior concerning growth and fork height compared to provenances/landraces from India (mainly South West India), Thailand, Malaysia, and Tanzania
 - Even superior compared to families from selected open pollinated trees in the provenances/landraces above (Monteuuis et al., 2011)
- Solomon Island (moist conditions), age 88 months
 - Landraces of Solomon Island superior concerning growth compared to a provenance/landrace from India (Nilambur), Thailand, Nigeria and Honduras (Pedersen, 2010)





Identification of potentially superior genetic material - summary

- Local provenances and landraces – if they show reasonably well performance
- Material from superior trees in local international provenance field trials (if available)
- Seed sources of south-west Indian origin would possibly always be of interest to include
 - E.g. material from clonal seed orchard in Tanzania with the South-west Indian Topslip provenance
 - Generally good growth but external stem quality variable between provenances in the region



Identification of potentially superior genetic material – summary

- Selected and tested seed sources
 - Clonal seed orchards with selected clones in Thailand
 - Seedling seed orchard material from Solomon Island
 - Tanzanian landraces (Kihuhwi, Mtibwa) at semi moist sites
- Clones from the “YSG Biotech” programme in Malaysia propagated from selected trees in BSOs
- Seed from provenance-progeny field trials converted into seedling seed orchards in the “YSG Biotech” programme if/when available



Doreen K. S. Gow¹
 Olivier MONTEUUIS²

**Status of the “YSG Biotech”
 program of building
 teak genetic resources
 in Sabah**

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Photo 1.
 Converting the “Provenance-progeny” trial of teak into a seed orchard.
 Photo Y. Naudou.

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- Goh & Monteuiis (2009)
- ongoing provision of propagating material of commercialised clones;
- provision of seed from several seed sources for 'establishing breeding bases elsewhere'
- provision of new suites of clones that have been developed from selections within the seed orchards established earlier, and from selections that can be made in the clone tests established late



A ramet of a Sabah teak clone in a plot (stand conditions) planted by QFRI in April 2002 near Mossman, Queensland.

At age 7 y:
 DBHOB – 25.4 cm,
 Total height – 21.4 m,
 Bole length – 13.4 m

Note high vigour, straight stem, natural pruning and thin short branches (all typical of this clone).

Plot mean data (10 trees):
 DBHOB – 21.8 cm
 Total height – 19.9 m,
 Bole length – 12.6 m

Photo: Olivier Monteuiis. Notes: Garth Nikles.



Conclusions: the genetic business plan

- Differences in especially survival and growth performance can be very large between potential seed sources
- The degree of provenance by environmental interactions may be substantial.
- The potential value of improving the applied planting material may be substantial
- The prediction of the performance of a certain provenance or clone at a given planting site based on e.g. climate match is uncertain.
- Necessary to setup local tests to find the most suitable genetic material.



Conclusions: the genetic business plan

- Results from the international field trial series can be used to concentrate on a manageable number of genetic materials that could be of interest.
- Two types of tests
 - Traditional tests coordinated by research organisations or as a cooperative effort between teak planting companies and organisations in the areas.
 - Local test set-up by teak planters by keeping precise track of applied planting stock at each planting sites and include alternative seed sources in a way that will allow easy comparison and simple future data harvest.





Conclusions: the genetic business plan

- In the absence of knowledge, it is advisable to plant diverse genetic material to avoid a failure with poorly adapted genetic material.
- Important to gain knowledge that will allow an increasingly smarter choice of seed sources in the future.



Conclusions: the genetic business plan

- Iterative process based on still better knowledge based on
 - what is generally known from international research
 - what is known from local experience in the area including local tests (if any)
 - an overview of potential seed sources / selected clones that are available locally or internationally (relevant in terms of time frame, scale and costs)
 - experience and data generated as part of the on-going activities
 - a pro-active approach to development of new seed source options (or clones) based on local (smart but low input) selection and/or more advanced coordinated effort
 - continuously adaption of the genetic business plan based on new information available locally and internationally.





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Micropropagation - An effective tool for mass propagation of quality planting stock of teak (*Tectona grandis* Linn. F.)

Shuchishweta V. Kendurkar
Principal Scientist

31 August 2011 at KFRI, Peechi, Kerala, India.

Plant Tissue Culture Division,
National Chemical Laboratory,
Pune



Cabinet

Uses of Teak wood



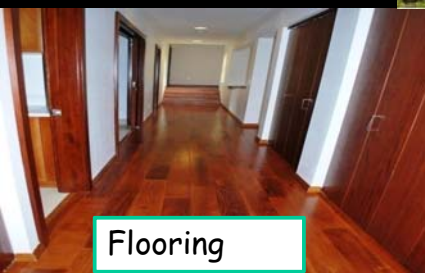
Venetian



Ship building



Furniture



Flooring

A Quality Timber



Container

Status of teak plantation in India



- ❑ First plantation in 1846, Nilambur, Kerala
- ❑ 8.9 million hectare of teak bearing forest in India
- ❑ 1.5 million hectare of teak plantation
- ❑ Divided into 5 subtypes:
Dry, Very Dry, Semi Dry, Moist, Very Moist
- ❑ Plantation target 50,000 plants annually



Extensive base work by Forest Departments on the following lines

- ❑ Identification of superior genotypes
- ❑ Establishment of germplasm banks
- ❑ Establishment of Seed Production areas
- ❑ Establishment of clonal seed orchards
- ❑ Standardization of silvicultural practices
(site matching, spacing, thinning methods, rotation, age and harvesting)
- ❑ Insect Pest Management



Mass propagation of Teak

Conventional methods

Natural regeneration through seeds

Vegetative propagation- first attempt by Fergusson,1938

- Forkert budding (Keiding and Bonnkind,1960)
- Patch budding (Rawat and Kedarnath,1968, M. Hussain and Somasundaram, 1975)
- Cleft grafting (Rawat and Kedarnath,1968)
- Root grafting (Dabral,1977)
- Rooting of cuttings (Lahiri,1974)
- Rooting of coppice shoots (Rawat *et al.* 1995)

Plantation targets and Conventional propagation

- ❑ Stumps raised from seedlings are used for large scale propagation
- ❑ Seed raised progeny shows variation
- ❑ Rooting of cuttings has limited scope for large scale production
- ❑ Gap between demand and supply
- ❑ Need for high quality propagules





Need for Clonal propagation

Teak exhibits high degree of inter and intra population variation in

- Growth performance
- Wood quality
- Susceptibility to diseases
- Age at first flowering

Growth and yield - Site Selection

Stem straightness, persistence of stem axis, branching and flowering - Genetic control



Clonal Propagation

Propagation to get true-to-type progeny

- **Macropropagation**

- ✓ Rooting of cuttings
- ✓ Grafting
- ✓ Budding

- **Micropropagation**

The process of mass propagation of selected clones via *in vitro* techniques.



Need for Clonal propagation

Teak exhibits high degree of inter and intra population variation in

- Growth performance
- Wood quality
- Susceptibility to diseases
- Age at first flowering

Growth and yield - Site Selection

Stem straightness, persistence of stem axis, branching and flowering - Genetic control



MICROPROPAGATION

Rapid multiplication/ cloning of desired mother plants in vitro

Advantages :

Faster propagation of difficult to propagate, rare, exotic newer, hybrid and transgenic plants.

Virus / disease elimination

Mass production all the year round

Easy transport / shipping to far off places

Micropropagation of Teak

- Selection of plus trees
- Collection of material
- Surface sterilization of budwood material
- Control of phenolics
- Initiation and Establishment of cultures
- Multiplication
- Rooting and hardening
- Field Planting

Studies on Teak Tissue Culture - Preamble

- ✿ Whether it is possible to propagate the mature trees in vitro ?
- ✿ Can the technology be applied to large scale propagation ?
- ✿ How tissue culture raised plants will behave in the field ?
- ✿ Are there any advantages to use this technology ?



Tissue Culture of Teak

- Work was initiated during late 70's at NCL, Pune in collaboration with Maharashtra Forest Development Corporation



- First report in 1980 - Successful Tissue Culture and plantlet from mature trees
- It was shown that **Yes** it is possible to propagate the mature trees in vitro

Status of Teak Tissue Culture In India

Gupta et al 1980

Mascarenhas et al 1987, 1993

Kendurkar et al 1991, 1999

Devi et al 1994

Nadgauda et al 1997, 2000, 2003

Yashoda et al 1999, 2003

Tiwari et al 2002

Fatima Shirin et al 2005

Kendurkar et al 2007

Tissue culture of teak at NCL - Milestones

1. First report on mature tree tissue culture (over 80 yrs.) - Gupta et al 1980
2. R & D for development of simple method for faster multiplication *in vitro* Mascarenhas et al 1987, 1993, Kendurkar et al 1991
3. Preliminary Field evaluation indicating higher biomass (height and girth) Mascarenhas et al 1987, 1993
4. Technology scale up and refinement for micropropagation of different genotypes. Nadgauda et al 1997, 2000, 2003, kendurkar 2007

5. Studies on cryopreservation of teak meristems Kendurkar et al, 1999

6. Transfer of technology to industries at National and International level

7. Molecular studies to test clonal homogeneity

8. Analysis of wood density and assessment of wood volume



Collection and processing of Budwood material

ELITE CHARACTERS

- TOTAL HEIGHT
- CLEAN BOLE HEIGHT
- NARROW CROWN DIAMETER
- TRUNK WITHOUT FLUTES
- SELF PRUNING OF SIDE BRANCHES
- GIRTH AT BREAST HEIGHT
- RESISTANCE TO DISEASE AND PESTS

Factors affecting micropropagation

- Genotype
- Season of collection
- Physiological status of explant
- Control of phenolics and contamination
- Physical and Chemical parameters

Refinement and Up scaling

- Reduction in number of steps.
- Optimization of chemical and Physical parameters.
- Improvement of multiplication rate.
- Development of ex vitro rooting and improvement in survival rates.
- Methods for successful transportation of plants.

EX VITRO ROOTING

ELIMINATION OF
IN VITRO
ROOTING STAGE

WEANING OF MICROPROPAGATED PLANTS

PROLIFERATING CULTURES

HARVEST MICROSHOOTS

IN VITRO

PLACE IN MEDIA FOR AUXIN TREATMENT

PLACE IN MEDIA FOR ROOTING

WAIT UNTIL ROOTING

OPEN CULTURE VESSEL

REMOVE SHOOTS

WASH TO REMOVE AGAR

PLACE IN SUITABLE SUBSTRATE

EX VITRO

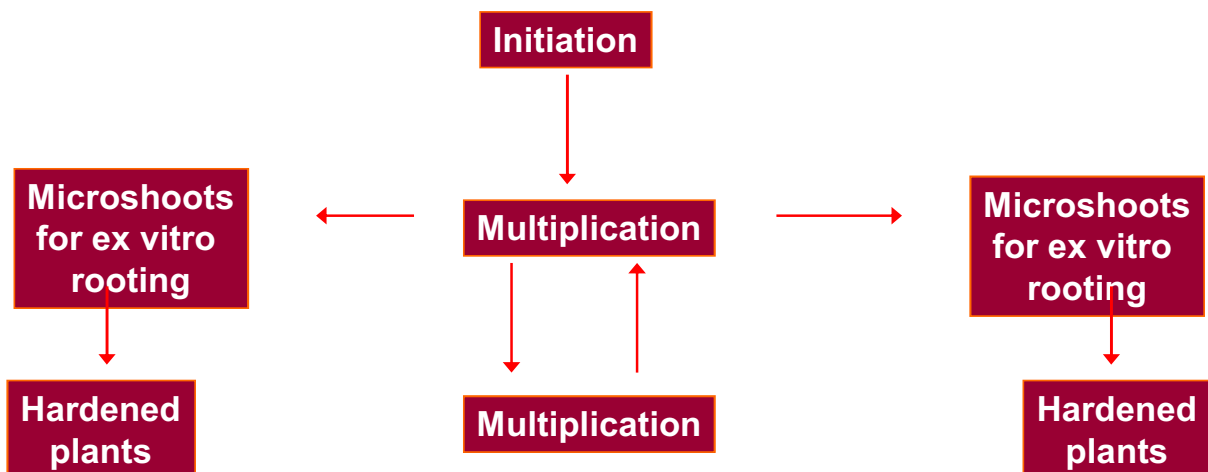
WASH WITH WATER

PLACE IN ROOTING COMPOUND

PLACE IN SUITABLE SUBSTRATE



Protocol for Pilot Scale Micropropagation



Transport of TC plants as Stumps

Stumps

- 2 – 4 cm of stem portion above the first pair of buds with tap root cut to the length of 20 to 25 cm

Tissue culture raised plants of teak (2000 nos.) were supplied as stumps to be planted at Raipur, Chattisgarh.

The tissue culture stumps sprouted (95%) and these were planted before the rains.



Application of protocol to different genotypes

- ✿ **Media**
- ✿ **Size of explant**
- ✿ **No. of explants per Culture vessel**
- ✿ **Season of multiplication, rooting and hardening**

FIELD TRIAL

To test clonal homogeneity

To assess the performance of tissue culture raised plants

To identify clones for suitable provenances

FIELD TRIAL AGENCIES

FOREST DEPARTMENTS

FOREST CORPORATIONS

AGRICULTURE UNIVERSITIES

PRIVATE SECTOR COMPANIES

FARMERS AND GROWERS

RESULTS

- ✿ **HIGHER BIOMASS**
- ✿ **EARLY ROTATIONS**
- ✿ **UNIFORMITY**



Thinning



Field trial on Teak

Site : Sangli

Spacing : 3m X 3m



Intercropping with Marigold



Field Trial on Teak- Sangli



Age four and half years old

Field Trial on Teak- Sangli

Age - 9 years



Intercropping with Turmeric

Wood density Analysis of Teak

$$\text{Basic wood density} = \frac{\text{Oven dry weight (Kg.)}}{\text{Oven dry Volume (m}^3\text{)}}$$

Drying of wood at 80⁰c

Volume estimation by water displacement method

Wood Density Analysis of Teak Age 9 years

	Wet Density Kg / m³	Dry Density Kg / m³
Control	860.30	620.51
TC raised	975.88	671.27

**27 Yr. Old conventional plantation density of
wood 551 Kg / m³ (Sanwo 1987)**

**Basic density = oven dry wt. / Oven dry vol.
Monograph on Teak Kg/m³
D.N.Tiwari, 1999**



**Table - II : Wood volume analysis (Projected)
Gandhinagar, Gujarat**

Clone	Av. Height (m)	Av. GBH (m)
NC-21	9.18	0.635
Average wood volume / ha after 6 years : 76.34 m ³ /ha		
Average wood volume conventional plantation after 20 years : 139 m ³ / ha		

$$\begin{aligned}
 \text{Volume of tree} &= [(G/4)^2] \times \text{height} \times 0.3 \\
 &= (0.635/4)^2 \times 9.18 \times 0.3 \\
 &= 0.0694 \text{ m}^3
 \end{aligned}$$

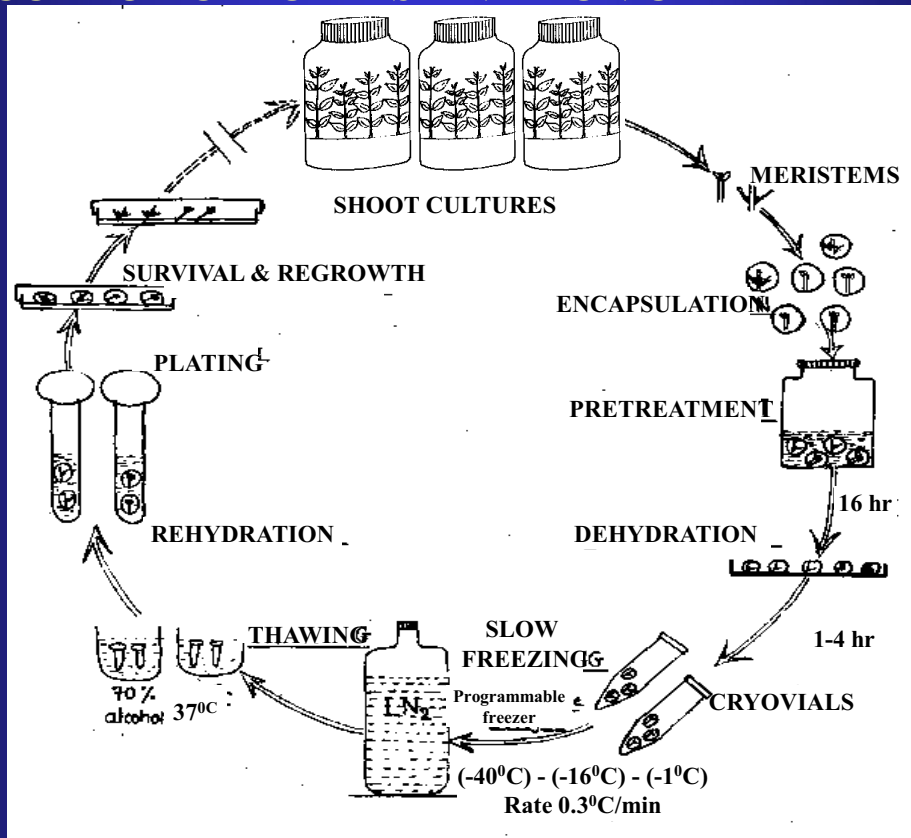
$$\begin{aligned}
 \text{Total No. of trees / ha} &= 1100 \\
 \text{Approx. estimated wood volume / ha} &= 76.34 \text{ m}^3 / \text{ha} \\
 \text{Av. Teak yield / ha after 20 yrs.} &= 139.00 \text{ m}^3 / \text{ha}
 \end{aligned}$$

Impact of Teak Plantation at Social, economic and environmental level

- Major benefit is improvement in environment
- Trees acted as wind barriers - Saving soil erosion
- Drop in temperature 3-4 degree C. and increase in the humidity
- Employment generation
- The branches, twigs and leaves etc are collected by the poor villagers
- Land between the plantation can be provided to landless farmers for cultivation
- Inter cropping with leguminous crops leading to capturing of nitrogen in soil.

Cryopreservation

PROTOCOL FOR CRYOPRESERVATION OF TEAK MERISTEMS

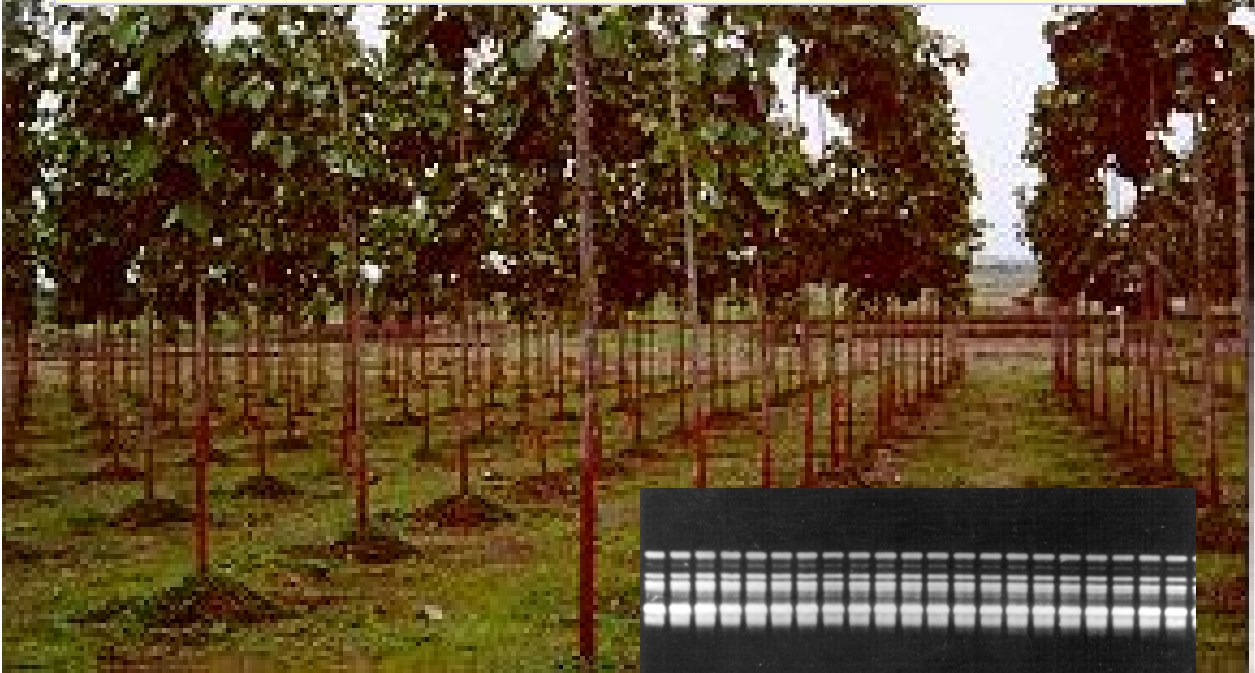


Kendurkar et al, 1999



Molecular marker analysis

Testing through molecular markers, clonal homogeneity of the micropropagated plants



Conclusion

- Whether it is possible to propagate the mature trees in vitro ?
- Can the technology be applied to large scale propagation ?
- How tissue culture raised plants will behave in the field ?
- Are there any advantages to use this technology ?

It has been demonstrated that it is possible to multiply mature trees in vitro and technology has been successfully used for large scale production of plants

Molecular markers Confirmed clonal homogeneity of tissue culture raised propagules.

Multi location field trials indicate uniformity and higher growth performance. Wood Density analysis is encouraging

Technology can lead to Significant gains



**Technology transfer
on
Micropropagation of Teak
at
National & International Level**



Future scope

- **Genetic improvement**
 - Marker assisted selection
 - Mass multiplication of superior genotypes

- **Genetic transformation studies**
 - Insect resistance
 - Pest resistance
 - Improvement of wood / timber quality

Growth Performance of TC Teak

- Planting Site
- Spacing
- Silvicultural management
- Clone



Thank You



SOIL MANAGEMENT IN TEAK PLANTATIONS

B. MOHAN KUMAR

Kerala Agricultural University

“Teak is the jewel than shines and shimmers in the diadem of
tropical trees”

-- Brandis



Outline

- Introduction
 - Plantation productivity scenarios, site quality deterioration
- Site fertility management
 - Chemical fertilizers
 - Biofertilizers
 - New systems of plantation management (NFTs)
- Quality aspects of fast grown teak
- Conclusions

Man-made forests

- Source of meeting the rising industrial and domestic wood requirements
- Ease pressure on tropical forests
 - “our doomed warehouses of global biodiversity” (JJ Ewel)
- World total ~60 million ha tropical plantations (1999)
 - Demand (55 million tonnes, Tg) and sustainable supply gap (41 Tg) timber in India: gap 14 Tg
 - Fuelwood gap 100 Tg

Increasing area under teak plantations

- Recent changes in land and tree tenure and improved access to markets
 - Encouraged cultivation by farmers
 - integral part of their farming systems
 - in small woodlots
 - in homegardens
 - or in mixtures with other trees and agricultural crops

Distribution of teak plantations

- India - about **1.3 million ha** [44% teak plantations]
- Indonesia (31%)
- Other countries of tropical Asia
 - Thailand (7%)
 - Myanmar (6%)
 - Bangladesh (3.2%)
 - Sri Lanka (1.7%)
- **Tropical Africa - ca. 4.5% of global teak plantations**
 - **moist West Africa, e.g. Côte d'Ivoire and Nigeria**
- **Tropical America (Brazil, Costa Rica, Panama, Trinidad and Tobago etc.) and Pacific Islands**

Commercial considerations

- Enhance overall profitability
- Shorter rotations
- Extension of farming into sites which are probably less suitable
- Modest growth rates: 4 to 8 m³ ha⁻¹ yr⁻¹ (Htwe, 1999; Cao, 1999).

MAI maximum and MAI at 50 years rotation age for different site classes (m³ ha⁻¹ year⁻¹)

Country	Best		Average		Poor	
	MAI (max)	MAI (50)	MAI (max)	MAI (50)	MAI (max)	MAI (50)
Côte d'Ivoire	17.6	9.5	12.2	7.5	6.8	4.3
India	12.3	10.0	7.9	5.8	2.7	2.0
Indonesia	21.0	17.6	14.4	13.8	9.6	9.6
Myanmar	17.3	12.0	12.5	8.7	5.9	4.3
Nigeria	23.8	13.3	18.5	9.0	13.1	6.8
Trinidad and Tobago	10.2	6.5	7.5	5.0	5.5	3.9

Estimates from yield tables [source: Pandey and Brown, 2000: Unasylva]

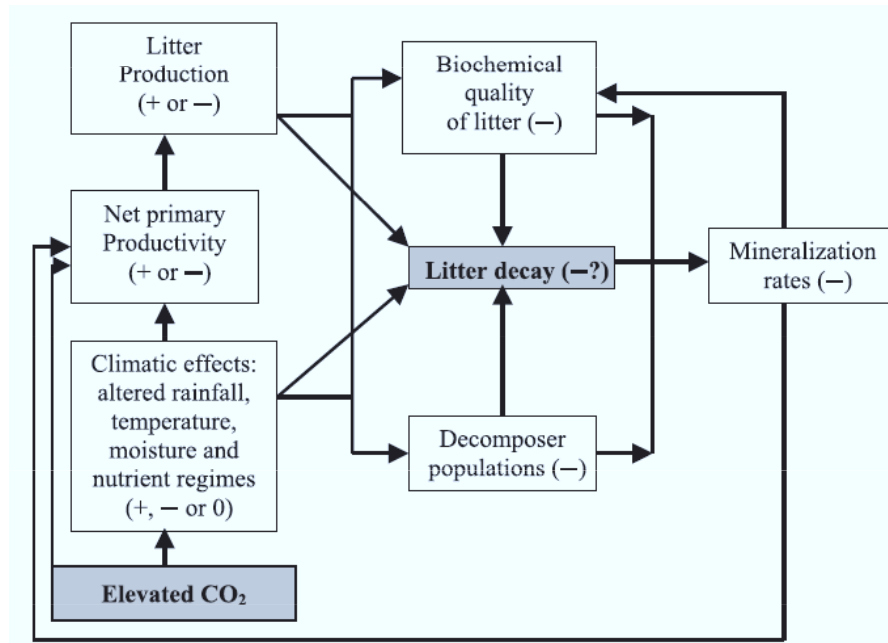
MAI at 50 = average age at harvest and MAI_{max} at the age of maximum volume production

Actual harvest yield from teak plantations is lower than the yields indicated

- Indonesia—average actual MAI at harvest age [rotation: 40 to 90 yrs]: $2.91 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ (FAO, 1986) as opposed to $13.8 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ from yield table projections
- Similarly, in India, based on the actual yield obtained from thinnings and final fellings in Konni in Kerala State [70-year rotation], the MAI was $\sim 2.5 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ (FAO, 1985); 2 to $7 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ for India (Bhat and Ma 2004)
- Central America, for a rotation length of 25 to 28 years, 10.2 to $13.3 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ (Arias 2005).
- Cost Rica MAI_{Vol} 11.3 to $24.9 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ (Pérez and Kanninen, 2005)
 - Final stand densities: 120 and 447 trees ha^{-1}
 - total volume over rotation of 268 to $524 \text{ m}^3 \text{ ha}^{-1}$
- **Are non-traditional locations better?** Higher productivity in the non-traditional areas (e.g. Latin America) than traditional teak growing areas

Decline in productivity during second rotation

- Harvest related nutrient exports and site deterioration
 - in short rotation plantations may far exceed the rate of replenishment by weathering of minerals in soils or by atmospheric inputs
 - harvesting of utilizable biomass in a 30 yr old stand resulted in the removal of 247, 41, 170, 632 and 198 kg ha^{-1} of N, P, K, Ca and Mg, respectively [Negi et al. (1995)]
 - annual uptake of 264 kg N ha^{-1} , 17 kg P ha^{-1} , and 132 kg K ha^{-1} for a 20 year-old stand, nearly all of it could be exported [George and Varghese (1992)]
- Losses may occur due to inter-rotation site management practices such as slash and burn, site preparation
- Global warming and the resultant accelerated soil organic matter (SOM) oxidation, faster degradation of nutrient-poor tropical soils



Conceptual model of the feedback/feed forward effects of rising atmospheric CO₂ levels on litter dynamics (symbols: '+', '-' and '0' indicate positive, negative and neutral effects) Source: Kumar et al. (2005: Global Env. Res.)

Uncertainty

- Can plantations be grown perpetually on the same site without risk to their vigour and rate of growth?
- What silvicultural techniques ?
 - **control of growing stock (density)**
 - **Site fertility management**
 - Techniques for soil fertility maintenance

Mineral nutrition

- Exacting species
- Intensively managed plantations (high density) are expected to place large demands on soil nutrient reserves
- Nutrient losses during harvest of short rotation plantations
 - exceed the rate of replenishment by weathering of minerals in soils or by input via precipitation

Paucity of scientific studies on teak nutrition

- Nutritional studies on teak were initiated as early as 1933 in Java (Coster 1933; Drees 1940) and 1934 in Nilambur (Schnepper 1934)
- The CABI abstracts lists only less than 25 studies on this aspect (**excluding those on teak nurseries**)
- **Inconsistent results: +,–, or 0 effects**
- Early authors found little or no beneficial effect on teak growth or that the effect was at best temporary

Raison d'être for negative or lack of responses

- Three factors, which may operate either separately or in unison
- Fertilisation may enhance the growth of competing understorey vegetation, especially in young stands
 - curtail fertiliser response through limiting availability of those nutrients supplied
 - suppress the availability other site resources such as moisture or light

Increased herbivore pressure

- Chemical fertilisers in general and N in particular, tend to enhance the palatability/nutritional quality of the leaves and twigs
 - added nutrients increase herbivory
 - greater pest incidence

Effect of fertilizer levels on pest incidence of 8.8-year-old *Ailanthus triphysa* stands in Kerala, India (source: Shujauddin and Kumar, 2003: For. Ecol. Manage.)

Fertilizer levels (N:P ₂ O ₅ :K ₂ O kg ha ⁻¹ per year)	Pest score (Visual score on a 0–9 scale at 4 years after planting)
0: 0: 0	1.03 a
50:25:25	0.97 a
100:50:50	0.64 b
150:75:75	1.44 c

Inherent nutrient supplying power

- Thirdly, if the inherent mineral nutrient supplying power of the site is high, then there may be little response to applied fertilisers.
- Long-term increase in soil fertility of repeatedly fertilised sites
 - nutrients stored in organic matter are released at an increased rate
 - increased rate of nutrient recycling will reduce the use efficiency of inorganic nutrients leading to their reduced retention, under low SOM
- Other factors such as stand density management, nutrient immobilisation and/or leaching may be important in stopping the fertiliser response.

Application of chemical fertilisers

- Under conditions of weed competition, pest incidence and/or moderate to high inherent soil fertility may not be beneficial.
- Conversely, in systems where the inherent fertility of the soil is lower, favourable response to fertilisers is almost certain.
- Hence fertiliser application to plantations should consider the site nutrient supplying power, stocking levels and silvicultural strategies, besides the potential for weed competition/pest incidence

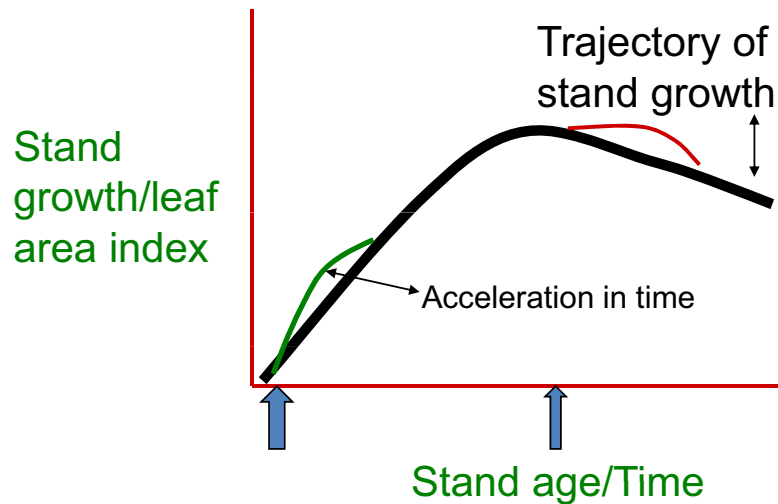
Affirmative responses

- Demonstrated that teak growth and basal area increment are positively correlated with nutrient additions
 - Kishore (1987) reported that diammonium phosphate (DP) significantly increased height growth of teak in the first 2 years after establishment, but no perceptible increase in radial growth
 - Prasad et al. (1986)- continuous fertilisation (for 5 years) of 10 and 20 year old teak plantations with 0, 150 or 300 kg ha⁻¹ N and 0, 75 or 150 kg ha⁻¹ P increased height and diameter, volume production increased only in the 10-yr-old plantation
- Favourable responses on poor sites
 - growth and basal area increment are positively correlated with nutrient additions --some parameters were stimulated, others were not affected

Fertiliser application to teak is a tightrope walking!

- Reported studies do not go beyond spasmodically evaluating height, diameter and/or basal area responses over short intervals (1 or 2 yr)
- Although positive response to the fertiliser applied in conjunction with thinning is legitimately expected, such studies are conspicuously absent in teak
- Info not available on how much fertilisers to be applied and at what frequency
- “Acceleration of stand growth in time” : Miller (1981) response to fertilisation- reduction in rotation length

Stand development model [arrows indicate fertilization]



Some fertiliser recommendations for teak

- Fertiliser application to teak has become a common practice in recent years
 - 163 kg urea, 375 kg Mussoriephos, 45 kg Muriate of potash, 105 kg quick lime and 373 kg of magnesium sulphate per ha recommended for young plantations in Kerala: two splits in the first year and four splits during second and third year (Balagopalan et al. 2001)
 - 30 to 40 g N, 15 to 20 g P₂O₅, and 15 to 20 g K₂O per plant per year during 2 to 5 years of plantation age and thereafter once in 3 to 4 years for 10 to 12 years (KAU 2002)
- Chemical fertilisers are expensive and often a potential source of environmental pollution

Biofertilizers

- Experimental studies in West Java indicated that arbuscular mycorrhiza fungi (AMF: *Glomus aggregatum*) promoted growth of three-month-old teak seedlings (Irianto and Santoso 2005).
- Phosphobacteria+AMF increased the survival and growth of teak seedlings
- *Azotobacter* gave the best performance with respect to shoot length, shoot weight, and leaf area (Swaminathan and Srinivasan 2006).
- Synergistic effects: application of calcium nitrate (CN), DP or CN + DP (250 kg ha⁻¹), inoculation of *Glomus caledonium* or composite teak rhizosphere VAM (250 to 300 spores/100 g soil) showed better height growth and foliar N and P levels on a poor site, two years after treatment (Ananthapadmanabha et al. 1998).

Organic matter addition

- Low organic matter turnover
- Bole fraction, in general accounts for about 50% of the total nutrient export.
- A slight reduction in the tree parts removed from the site would definitely alter the rate of nutrient export.
- Returning leaves and small twigs to the site at the time of harvest may be a worthwhile option to restrain nutrient export from the site.

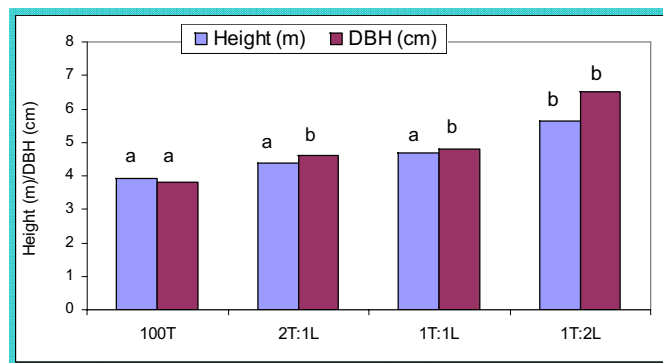
New systems of plantation management which mimic the natural ecosystems

- Many natural forests contain simultaneous or sequential mixtures of N fixing and non-nitrogen fixing species
 - Acacia and eucalyptus
 - Alder and conifers
 - Leguminous cover crops are widely used in the rubber and other plantations
- but use of woody legumes as a source of N nourishment to forest plantations has been less frequent

Mixed species plantations: advantages

- Adoption of mixed species plantations
 - increased productivity
 - plantation health (reduced losses due to disease and insect attacks)
 - sustainability
 - diversification of wood products
 - greater C sequestration potential

Replacement series expt. on teak and N-fixing trees



Mean height and diameter at breast height (DBH) of teak saplings at 44 months of age as affected by relative proportions of teak and *Leucaena* in the mixture [source: Kumar et al. 1998: Agroforest. Syst.]

❖ teak growth (height and diameter) increased linearly as the proportion of *Leucaena* increased

Teak+*leucaena* mixture

- At 44 months after planting, teak in the 1:2 teak-*Leucaena* mixture was 45% taller and 71% larger in diameter at breast height than those in pure stands.
- Facilitative production principle- N fixing species may improve the environment experienced by teak
 - total soil N and available P increased with increasing relative proportion of *Leucaena* in the mixture.
- Complementary resource use
- Species growing in mixture can potentially compete with one another for site resources such as light, water and nutrients
 - Teak being shade intolerant, selection of appropriate species with compatible crown form and growth characteristics is critical.
- Interaction between site quality and the additional quantities of N fixed by the legume/actinorhizal component

N₂ fixing trees: a viable silvicultural option for stimulating early teak growth, especially on unfertilized sites

- A 50% mixture (alternate rows—teak and NFT) is optimal
- Rationale—in a conventional 50-year-rotation of teak, first mechanical thinning reduces density by 50% [~ 5 years]
 - Teak density in a monospecific stand after the first mechanical thinning will be at par with that of a 1:1 binary mixture of teak and NFT
- No merchantable yield at the first mechanical thinning
- N-fixing species planted in the interspaces may yield substantial quantities of firewood, small timber and green leaves
- Judicious management of NFTs—selection of appropriate NFTs, inoculation with the appropriate strains of *Rhizobia*, and the cultures of arbuscular mycorrhizal fungi (AMF), pruning etc.

Better height and volume increments

- *Eucalyptus saligna* with *Acacia mearnsii* (Smith et al. 1989) and *Albizia falcataria* (syn. *Paraserianthes falcataria*; DeBell et al. 1989; Binkley et al. 1992).
- *Eucalyptus globulus* grown in association with *Acacia mearnsii*-- Khanna (1997)
- *Terminalia amazonia* in combinations with *Inga edulis* (Nichols et al. 2001)

Quality aspects of fast grown agroforestry teak wood vs. conventional teak

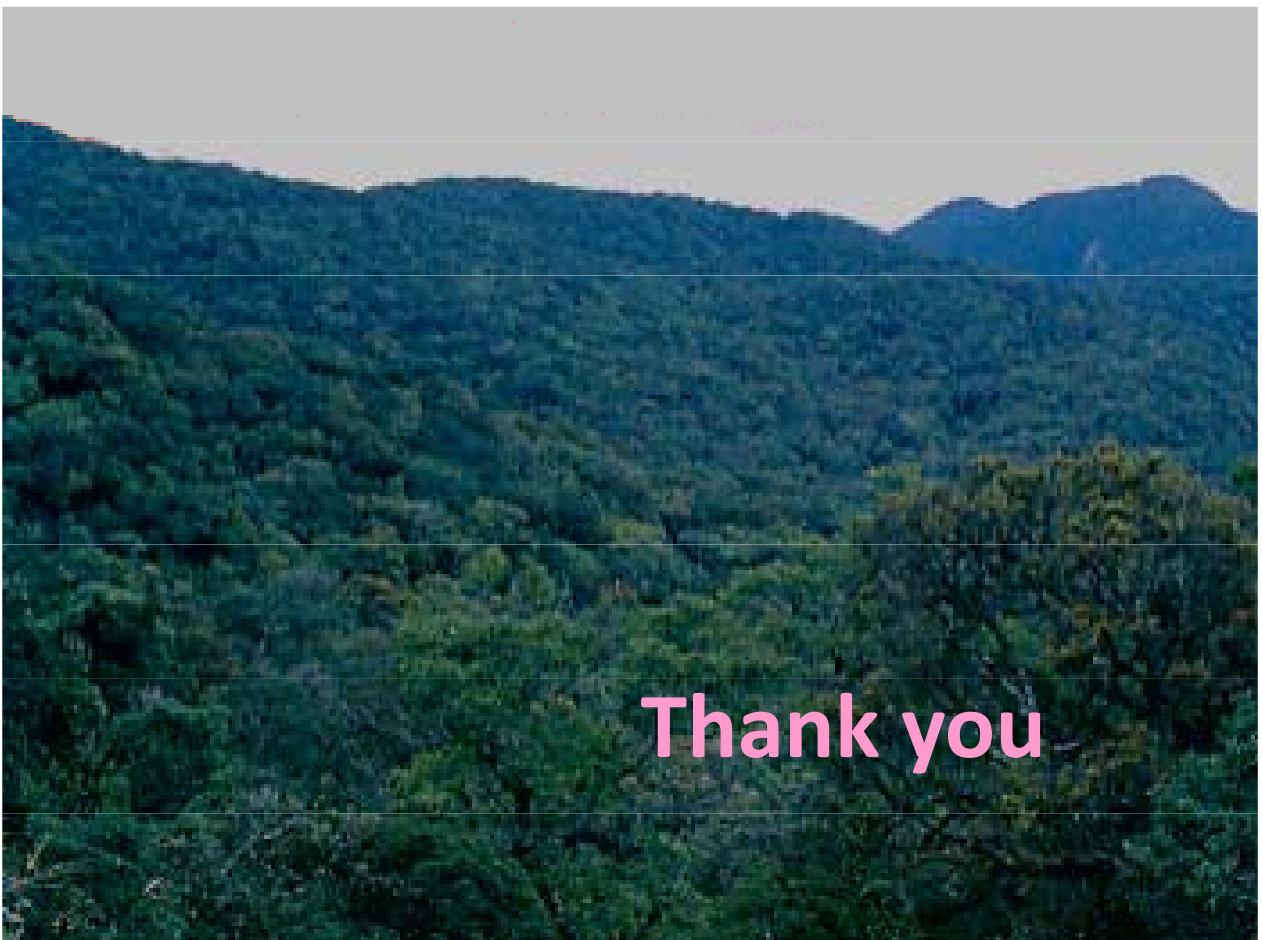
- Fertilization and irrigation of the associated trees/crops make intercropped teak grow faster than teak monoculture.
- Teak growth teak+rice system was significantly ($p>0.05$) more than in sole plantation-- Sharma et al. (2011)

Timber quality of fast-grown teak

- **Prevailing dogma:** teak timber from agroforestry would be of inferior quality than conventionally grown teak wood.
- Bhat (2000) evaluated certain wood properties of fast-grown teak to determine the quality of timber from intensively managed plantations.
- Fast-growing dominant (phenotypically superior) trees yielded a higher percentage of heartwood per tree during the juvenile period (up to 21 years), and the differences were not significant in the mature period (55 and 65 years).
- Faster growth also had very little effect on the strength of timber from 13-, 21-, 55- and 65-year-old plantations.
- Judicious fertilizer application thus can be advantageous in terms of heartwood volume per tree and timber strength.
- **Juvenile wood from intensively managed plantations, however, may differ from traditional teak wood with respect to grain and texture, thus influencing the market value of the timber.**

Implications for managing teak stands

- Fertiliser application (chemical or biological) in young stands prior to canopy closure or in conjunction with thinning that open up canopies in older stands, seems indispensable to sustain productivity
- Chemical fertilizers may not be beneficial
 - Under conditions of weed competition, pest incidence and/or moderate to high inherent soil fertility
- In systems where the inherent soil fertility is low, favourable response to fertilisers is almost certain
- Fast growth may not have any adverse effect on mechanical properties of timber, but grain size and arrangement may be inferior



Forest-level management planning

Juha Lappi

Finnish Forest Research Institute

Suonenjoki Research Station

stand level planning

maximization of net present value

- inputs and outputs have fixed prices

money:

- perfect capital market:
- money can be saved and borrowed at the same interest rate
- connections between stands -> forest level planning

Forest-level planning

- Total utility of a given forest area is dependent on the total time patterns of all aggregated inputs and outputs

The main phases of a planning process (Kangas et al. 2008)

- (i) Data acquisition
- (ii) Clarifying the criteria and preferences of the decision makers
- (iii) Generating the alternative treatment schedules and predicting their consequences
- (iv) Producing efficient production programs for the forest area
- (v) Choosing the best production program according to criteria specified in (ii)

A forest level planning approach: simulation & optimization with linear programming

used in:

- GAYA/J in Norway
- MELA in Finland
- SIMO in Finland

- MELA is using linear programming package JLP
- GAYA/J is using linear programming software J (newer version of JLP)
- SIMO is also using J

Simulation of forest development

- simulation done for each treatment unit (stand)
- planning period divided into subperiods (e.g. five ten year subperiods)
- treatments occur at the beginning or in the middle of each subperiod
- a special treatment: do nothing (let grow)
- other treatments: 'thinning with intensity x', 'clear cut', 'plant with x seedlings'. 'fertilize'
- Between the possible treatment points, the development of each treatment unit is predicted using development models.
- models can be at stand level (GAYA/J) or at tree level (MELA)

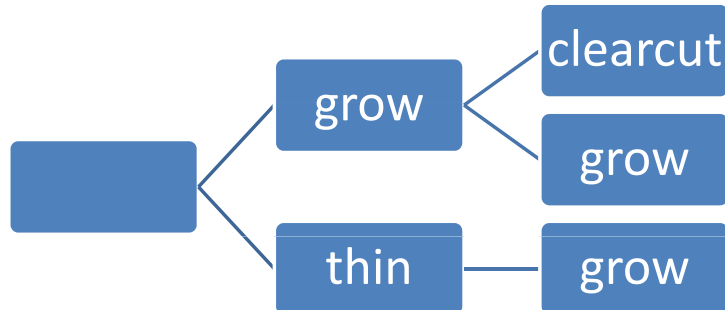
models needed for

- diameter growth
- height development
- mortality
- volume
- timber quality etc

Needed also

- timber prices
- harvesting and transportation costs
- interest rate
- These can be attached to schedules either at the simulation phase or at the optimization phase

- Treatment schedules form a tree structure.



- The simulator and data need to be compatible

$$\text{Max } z_0 = \sum_{k=1}^p a_{0k} x_k + \sum_{k=1}^q b_{0k} z_k \quad (1) \text{ (objective)}$$

subject to

$$c_t \leq \sum_{k=1}^p a_{0k} x_k + \sum_{k=1}^q b_{0k} z_k \leq C_t \quad (2) \text{ (utility constraints)}$$

$$x_k - \sum_{i=1}^m \sum_{j=1}^{n_i} x_k^{ij} w_{ij} = 0, k = 1, \dots, p \quad (3) \text{ (definition of } x_k \text{)}$$

$$\sum_{j=1}^{n_i} w_{ij} = 1, i = 1, \dots, m \quad (4) \text{ (area constraints)}$$

$$w_{ij} \geq 0, i = 1, \dots, m, j = 1, \dots, n_i$$

$$z_k \geq 0, k = 1, \dots, q$$

- The identity of treatment units is preserved throughout the planning horizon.
- -> type *Model I* in the *Model I / Model II* terminology
-
-
- There are as many area constraints as there are treatment units in the data.
- The difficulty of solving a linear programming problem is generally proportional to the number of constraints.
- JLP/J is using generalized upper bound technique to take care of area constraints-> very efficient

Examples: i) Sustainable Forestry

- 5 subperiods
- $npv.0$ is the total net present value discounted to the beginning of the planning period
- $income.1$ be the net income during first subperiod, etc.
-

sust=problem()

$npv.0 == \max$

$income.2 - income.1 > 0$

$income.3 - income.2 > 0$

$income.4 - income.3 > 0$

$income.5 - income.4 > 0$

/

Final state

- A problem is that the incomes may decrease substantially after the planning period.
- This is prevented by adding constraint.

$$\text{npv.5} - \text{npv.0} > 0$$

- where npv.5 is the net present value of incomes after the planning period
-
- The simulator needs to be able to calculate the net present value of the incomes for each treatment schedule after the planning period (this is needed also in npv.0).
- i) use stand level optimization is applied at the final state,
- ii) standard silvicultural recommendations are applied.
- Thus the simulator is doing computations also after the planning period, but there are no branching of schedules after the planning period.
- Another, more simple constraint for the final state is:
- $\text{vol.5} - \text{vol.0} > 0$

Goal programming

```
gp=problem()  
sp.1 + sl.1 + sp.2 + sl.2 + sp.3 + sl.3 + sp.4 + sl.4 + sp.5 + sl.5 == min  
income.1 - sp.1 + sl.1 = 800000  
income.2 - sp.2 + sl.2 = 850000  
income.3 - sp.3 + sl.3 = 900000  
income.4 - sp.4 + sl.4 = 1000000  
income.5 - sp.5 + sl.5 = 1100000  
npv.5 > 50000000  
/
```

- The 'sl' variables are slack variables and 'sp' variables are surplus variables. This problem requires that the sum of absolute deviations from the target values are minimized. Deviations at different subperiods can also have different weights.

Domains

- Constraints for a subset of treatment units using 'domains':

distance_to_town.le.15:

vol.1>2500

vol.2>2500 etc.

Solution of the Linear Programming Problem

- weights of schedules, w
- values of the z variables
- Using weights of the schedules, the values of the aggregated x -variables can be computed for all x -variables simulated by the simulator
- If there are binding constraints there will be split treatment units in the solution, i.e., there will be weights which are between zero and one.
-> round to an approximate integer solution

Shadow prices

- shadow prices tell the marginal properties of the solution
- The shadow prices of the area constraints tell how valuable the treatment units are compared to each other.
- The shadow prices of different x variables tell the value of the variable.
- (these can be compared to the assumed prices)
- The reduced costs of z variables which have value zero at the solution tell how the objective function will change if we force the variable to get a nonzero value

Conclusions

- Is this approach useful in forest level planning of teak plantations?
 - i) Are there available enough data about plantations?
 - ii) Are there available good-quality (stand level or tree level) growth models which take into account different treatments?
 - iii) Can prices of inputs and outputs be predicted?
 - iv) Is there a simulator available? If not, who would make it?

When a simulator is available, optimization can be done using J software.
- This approach is most useful when the age structure is not even

**HEALTH AND SUSTAINABLE
MANAGEMENT IN TEAK**

Dr. V. V. Sudheendrakumar
Forest Entomology Department

Teak is indigenous to

India –32 %

Myanmar- 59%

Thailand- 8.9%

Laos- 0.1%

Global distribution of teak plantations

Asia: 2.25 million Ha

Africa: 1,45,000 Ha

Latin America: 65,000 Ha

Now cultivated in 36 countries

TEAK

India : 1.5 million ha plantation

Kerala: 78000 ha

Planted in Kerala (Nilambur) in 1842

PRODUCTIVITY



Site quality
issues

Pest Problems

Different types of pests

Insect pests can generally be classified as defoliators, sap suckers, leaf miners, borers, root feeders etc depending upon their mode of feeding.

Defoliators:

Insects coming under this category feed on the leaf either completely or partially, which affects the growth of plants sometimes leading to the death.

Sap suckers:

In this group mostly the adult insect feeds on the plant surface like stem and leaf and sucks the sap from the plant leading to wilting of leaves or even the plant.

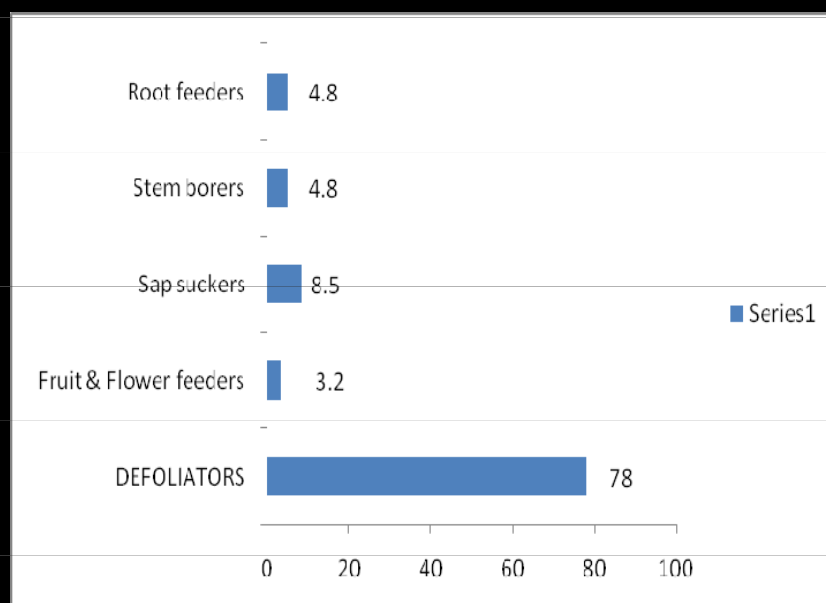
Different types of pests

Leaf miners: Insects of this group construct mines in leaves and feed within it damaging the leaves.

Borers: Insects of this group enter into the bark/stem of the plant and construct tunnels or grooves and remain there and feed within tunnels.

Root feeders: These are generally soil borne insects feeding the tender roots of plants and leading to the death of plant in most cases.

Teak has about 187 species of insects associated with it



Major Plantation Pests of Teak

Skeletoniser: *Eutectona machaeralis*

Sapling borer: *Sahyadrassus malabaricus*

Trunk borer: *Alcterogystia cadambae*

Defoliator: *Hyblaea puera*

TEAK SKELETONISER

Eutectona machaeralis
(Pyraustidae: Lepidoptera)



- Known as teak skeletoniser
- defoliate teak in plantations and nurseries.
- Larvae feed on the green matter of leaves retaining the veins intact. an important pest in plantations not a serious problem in nurseries.

Eutectona machaeralis



India
Myanmar
Bangladesh
Sri Lanka
Philippines
China

Paliga damastesalis

Java
Malaysia
Thailand
Andaman Islands in India

Eutectona machaeralis- Teak skeletoniser



Management Options ??

- Economic impact yet to be established. Major pest in dry zones
- In Kerala the outbreak occurs during the non growing season

Sapling borers

Sahyadrassus malabaricus

-Recorded in Kerala

Phassus signifer-

Recorded in Thailand, Myanmar



Sapling borer

Sahyadrassus malabaricus



Distribution: southern India

- Infest saplings only
- A moderate pest
- Borer hole seen about 30cm above soil level

Economic Impact

Saplings break at borer hole point during windy season

Control required in high value plantations -
Individual trees to be targeted

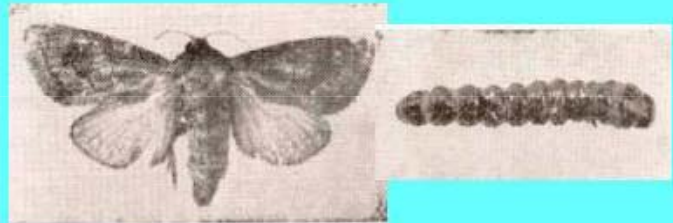
Weed removal reduces chances of infestation

Control

- Remove the tunnel cover and apply a contact insecticide on the tunnel mouth
- Use a contact insecticide

Teak trunk borer

Alcterogystia cadambae
(Lepidoptera: Cossidae)



Trunk borer
kannankuthu

Alcterogystia cadambae



Teak trunk borer infested trees

Alceterogysta cadambae

- Distribution in southern India
- Plantations closer to human habitations infested
- Mechanical injury on bark favours establishment of the pest on trunk
- Trees above 10 year old are generally attacked

Preventive measures

- Clear felling of all heavily infested trees in the plantation
- Extract heavily infested trees
- Keep healthy trees without mechanical injury on bark

Bee hole borer *Xyleutes ceramicus* (Lepidoptera: Cossidae)

Distribution:

Myanmar, northern Thailand

Central Java

Sabah, Malaysia

Control:

Mechanical removal of the larvae by scraping off the infested bark

Pheromone traps

TEAK DEFOLIATOR

Hybalaea puera

(Hyblaeidae: Lepidoptera)

Teak defoliator



Moth



Larva

TEAK DEFOLIATOR DISTRIBUTION

Asia Pacific

Australia, Bangladesh, Cambodia, China, Fiji, India, Indonesia
Japan, Laos, Malaysia, Myanmar, Nepal, Papua New Guinea
Philippines, Ryukyu Islands, Samoa, Solomon Islands
Sri Lanka, Taiwan, Thailand, Vietnam, Africa
Malawi, South Africa, Uganda

Central America

Costa Rica

Honduras

Caribbean

Cuba

Dominican Republic

Jamaica

Trinidad and Tobago

South America

Brazil

Pest outbreaks have occurred recently in Costa Rica and Brazil. The trend indicates that the teak defoliator is emerging as major pest in teak plantations around the world

Bangladesh
Indonesia
Thailand
China
Taiwan
Malaysia
Papua New Guinea
Philippines
Solomon Islands
Sri Lanka



Teak defoliator infestation in nursery



Initial build-up of teak defoliator

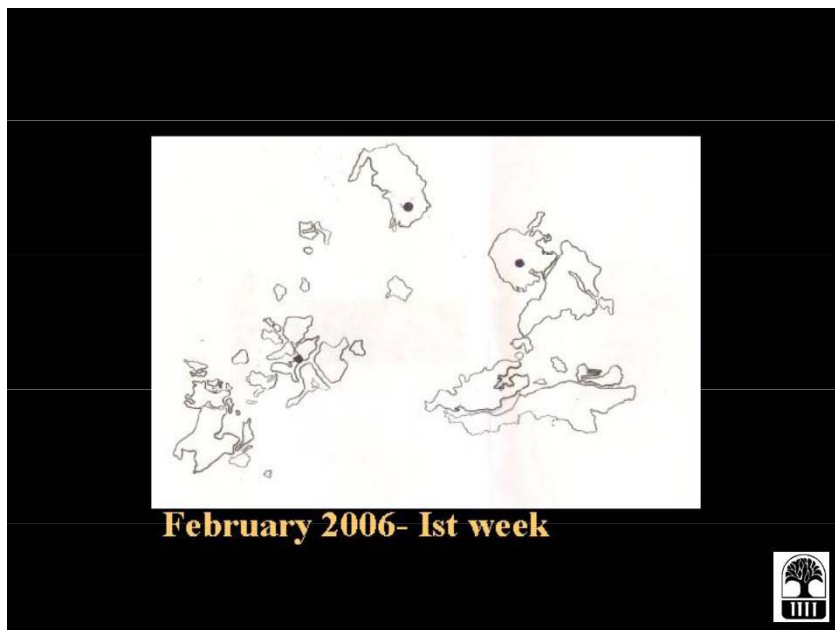
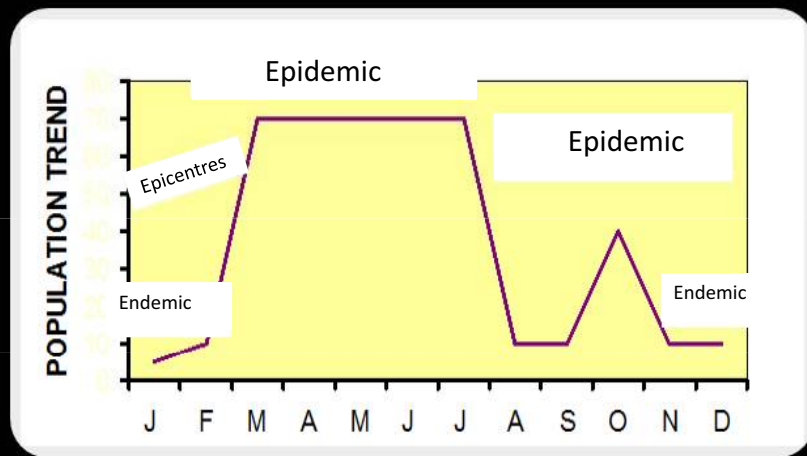


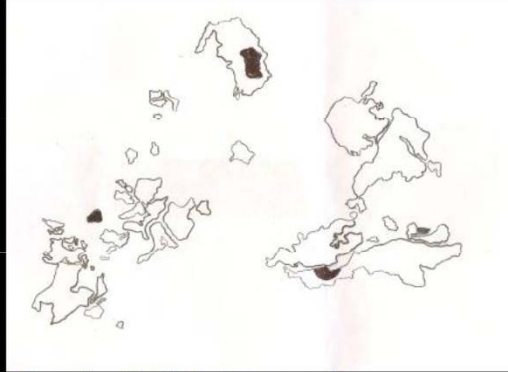
2nd instar larva



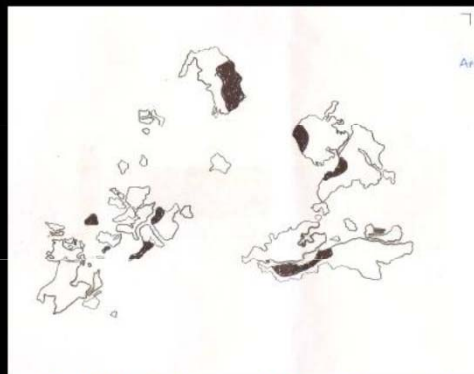
Teak leaf with several larval folds

Seasonal incidence trend and types of population





March 2006- 1st week



April 2006- 1st – May II week





The impact

Invisible impact

Defoliation results in loss of
in about 44 percent of the
potential volume increment
in young teak plantations

Visible impact

Terminal shoot damage leading
to forking in saplings and small
trees

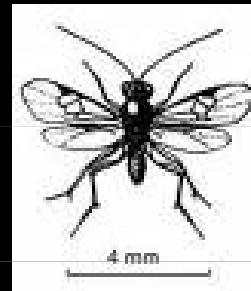
Pest management options

Chemical pesticide application is not advocated for environmental reasons.

Biological control

A wide variety of natural enemies exists

Natural enemies



Microbial pathogens

KFRI discovered a nucleopolyhedrovirus disease on teak defoliator in 1988

**Nucleopolyhedrovirus (NPV)
(Baculovirus)**



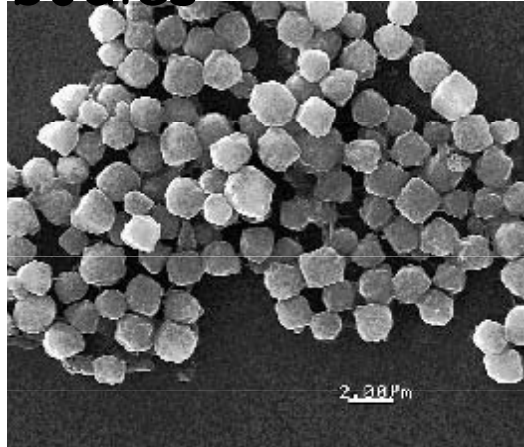
NPV infected and dead larva in field

Introduction

Baculoviruses

- DNA Virus
- Known exclusively from insects
- 800 Baculovirus isolates - from 400 host species
- Highly host specific

Viral occlusion bodies



Mode of infection

1. Larva accidentally feeds on teak leaves contaminated with HpNPV
2. The virus enter the body of the larva
3. The virus multiply within few cells of larval body. The larval body gets filled with virus particles.
4. Larva dies within 72-96 hours
5. The larval body breaks and the virus is liberated into the environment

Using HpNPV as a biopesticide

- **Mass production**

Host cultur maintenance

Virus multiplication

- **Formulation**

- **Field testing**

- **Safety aspects**

HpNPV MassProduction Method

A unique method for mass production of HpNPV was developed

Using larvae of *H. puera* reared in the laboratory on artificial diet

Host culture



Ist instar larva



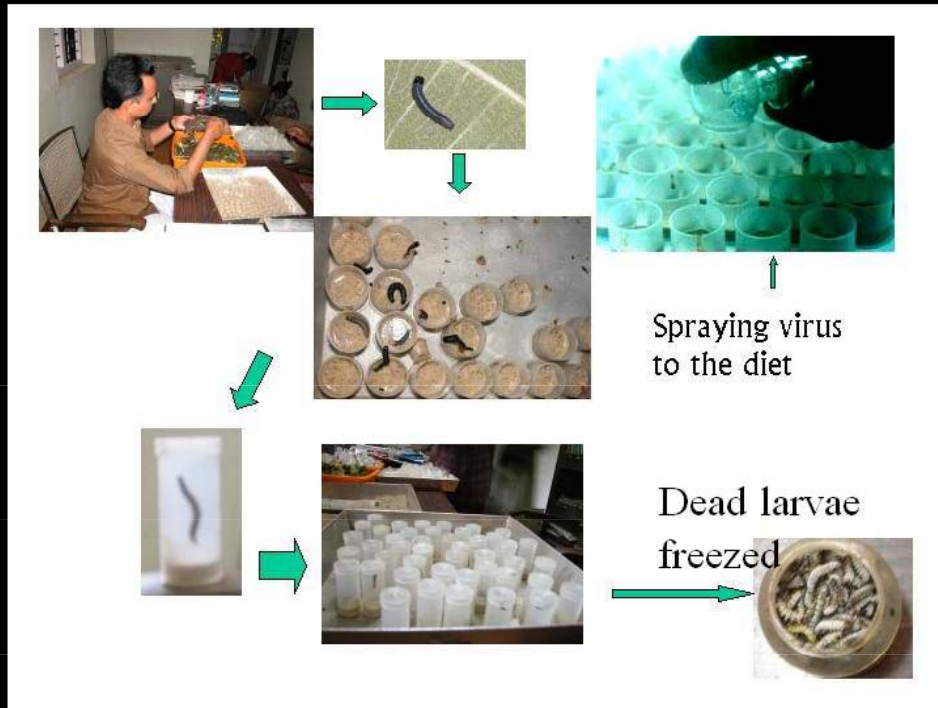
Rearing *H. pueri* on artificial diet



3rd Instar larvae transferred to artificial diet



HpNPV Mass production



Masceration
Filtration
Centrifugation



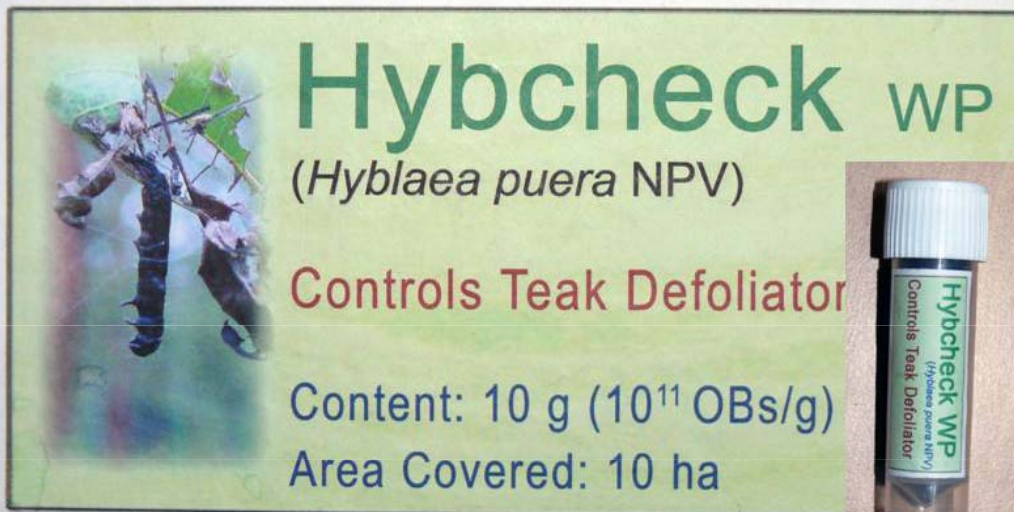
Formulation



Wettable powder
formulation



HPNPV FORMULATION



Hybcheck WP
(*Hyblaea puera* NPV)

Controls Teak Defoliator

Content: 10 g (10^{11} OBs/g)
Area Covered: 10 ha

Hybcheck WP
(*Hyblaea puera* NPV)
Controls Teak Defoliator

SAFETY TESTING OF THE WP FORMULATION OF HpNPV

**Cytotoxic effects of formulated HpNPV
tested in three cell lines : (Hafkine Institute)**

1. Hep-2 (human- larynx)
2. Vero (African Green Monkey- kidney)
3. Sf9 (*Spodoptera fugiperda*- ovary)

**Formulated HpNPV has no deleterious
effect on the above cell lines**

FIELD APPLICATION

Insect stage dependent dose

-Lower the stage lower the dose

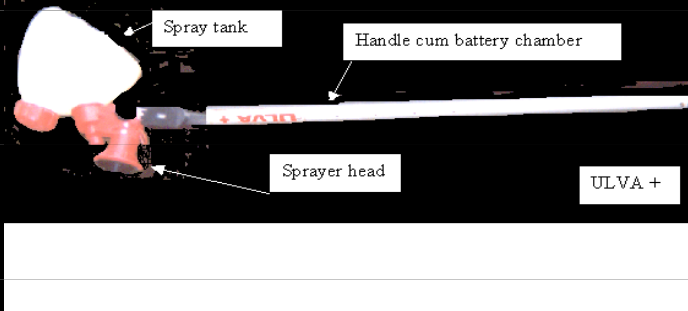
Sprayer systems for NPV application



Ultra low volume sprayer



Ulva fan



ULVA PLUS- Hand held



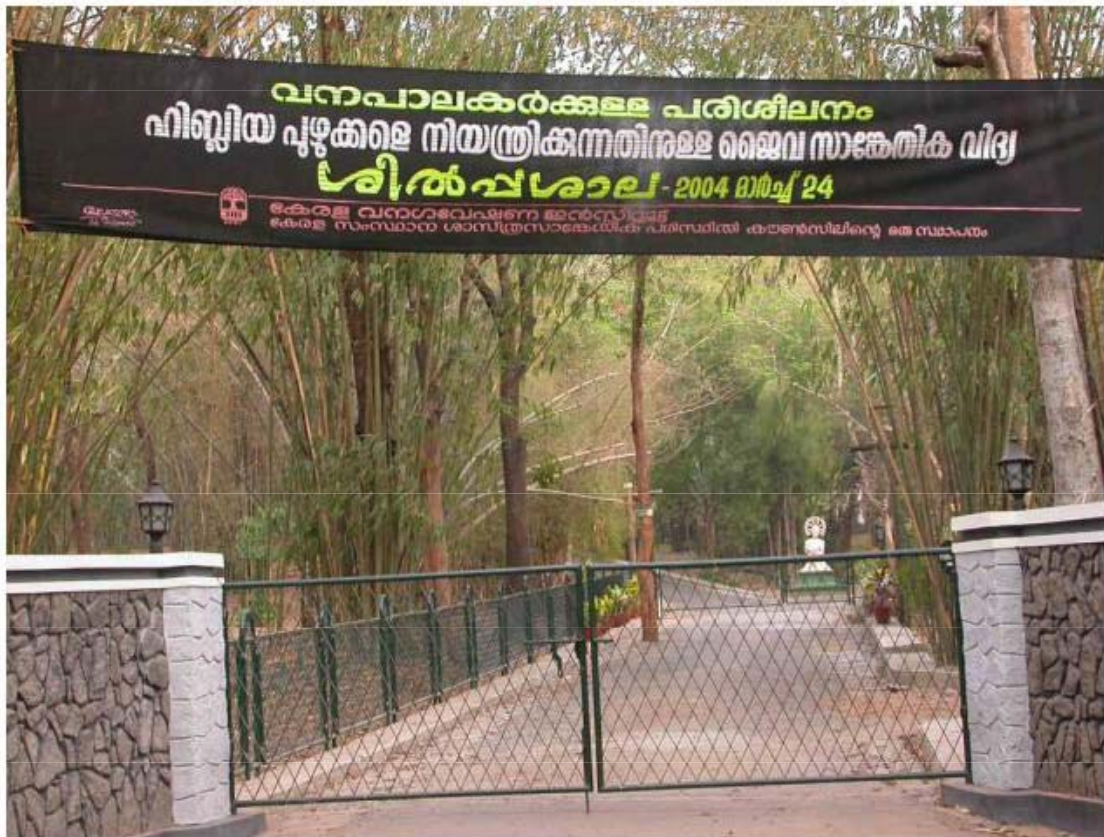
High volume sprayer



Landscape level management



Technology Transfer



CF Central Circle inaugurating



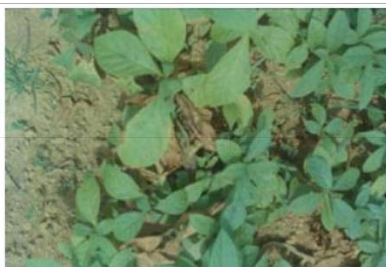
Prospects

- **Hybcheck : an ecofriendly indigenous biopesticide**
- **a natural product- no genetic manipulation**
- **fast action- kills defoliator larvae in 72 hours**
- **absolutely safe to non-target organisms**

Nursery Pests White grubs

White grub- *Holotrichia*- attack
in teak nursery bed

Scrabaeidae: Coleoptera



→ Grub

- White grub infestation is common in teak nurseries.
- the roots of seedlings are attacked by the grubs and infestation occur in patches.
- Infested seedlings show symptoms of wilting
- On digging the soil, the white coloured grubs can be seen in the nursery bed.

Holotrichia sp	Distribution-India
H. consanguinea	Maharashtra,
H. insularis	Bengal, Orissa
H. serrata	
H. fissa	Kerala

White grub infestation reported from
Indonesia, Bangladesh and Sri Lanka

Control

Soil application of granular insecticide

- Diazinon 10G (200g/ bed)
- Phorate 10G (20g/bed)
- Carbofuran 3G (70g/bed).

Diseases of teak

Bacterial collar rot

Pseudomonas tectonae

A nursery disease

The collar area just above the ground shows shrinking



Top leaves become flaccid and drooped.

Scorching of leaves with pronounced symptoms of wilting The wilted seedlings die soon die



Bacterial collar rot

- A nursery disease
- The collar area just above the ground shows shrinking
- Top leaves become flaccid and drooped.
- Scorching of leaves with pronounced symptoms of
- wilting
- The wilted seedlings die soon

Control

Application of Plantamycin 0.01
% (a.i.)

Avoid water logging in the
nursery bed

Leaf Blight- *Phoma glomerata*

Infection prevalent in nurseries

water soaked grayish brown patches
on leaves

The blighted leaves often show holes
in the infected portion

The infected leaves dry up
and are eventually shed.



Control

Removal of infected plants helps to prevent the disease spread

Application of Dithane M-45 (0.1%) is found effective in controlling disease.

Bacterial wilt

Pseudomonas tectonae: *P. solanacearum*

teak plantations varying from 6-month-old to 2-year-old infected

Disease incidence after the onset of monsoon showers

Bacterial wilt

Control

- Prophylactic measures are recommended
- proper sanitation methods stop development and spread of the disease
- The affected plants should be uprooted carefully and burnt
- Planting in water-logged areas should be avoided
- The soil at the site of the infected plant should be drenched with Plantamycin 0.01% (a. i.).

Pink disease (Stem canker)

Corticium salmonicolor

Recorded in Kerala and
Karnataka states
Prevalent in
1- to 5-year-old teak
plantations



Fig. 4. Pink disease affected teak plants

Pink disease

Infection on stem kills inner bark

canker characterised by pink encrustation develops

The portion of shoot above the canker is killed outright.

Epicormic shoots develop below canker one of which becomes leading shoot

The bark at the canker shows longitudinal splitting during the dry weather

Chemical Control

Bordeaux mixture (10%)

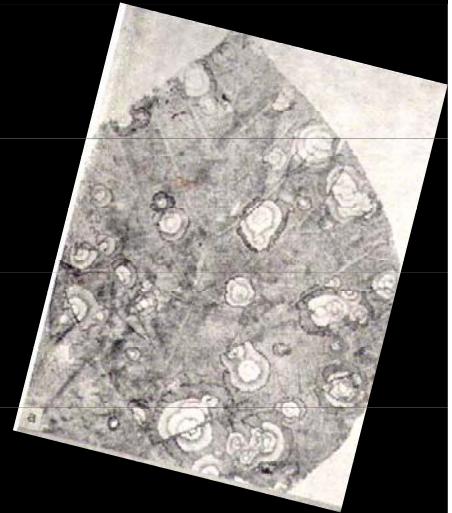
In the case of heavily infested canker application of a systemic fungicide like Calixin (tridemorph 0.1% a.i.)

Phomopsis leaf spot disease

Phmopsis tectonae and *P. variosporum*

The damage high in nurseries

Infection prevalent during August-September and upto December



Phomopsis leaf spot

Spots first appears as minute dark brown dots, 2-3 mm across, during late August.

The spots enlarged to 5 to 8 mm in diameter and became light pale brown in colour with a dark brown outline

The spots grow outwards and forms one to three dark brown concentric rings

The leaf spots cause considerable damage to the photosynthetic area

Colletotrichum Leaf spot disease

Colletotrichum state of *Glomerella cingulata*

common occurrence in plantations

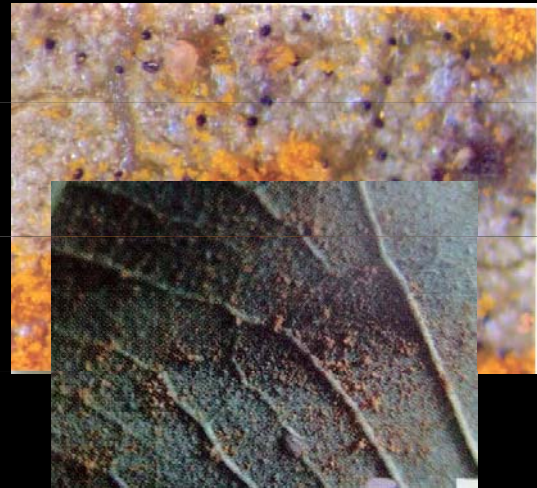
It usually appears on mature leaves during the monsoon

Trees of all age groups are susceptible to this disease



Leaf rust –

Olivea tectonae



Affect nurseries as well as plantations in dry areas

August to February.

Leaf rust

Presence of scattered dull green flecks on upper surface of affected leaves

These flecks turns necrotic in due course and appears as small brown spot

Causes premature defoliation affecting growth

Application of foliar sprays of sulphur based fungicides is recommended



Dendrophthoe falcata var. *pubescens*

Mistletoe-

angiospermic parasites found on teak

The most common and harmful

seen throughout Kerala

Heavy infestation results in death of the trees

Disease management (Nursery)

1. Cultural

Regulation of seedling density,
shade, water regime

Good growing medium

2. Chemical

Contact fungicides

Systemic fungicides; Bactericides

3. Biological

Antagonistic organisms

(*Trichoderma* spp.,
Pseudomonas fluorescens)

Mycorrhizae (VAM)

Plantation

Cultural:

Soil work; weeding; pruning

Physical removal of *Loranthus*

Chemical:

Fungicides; Bactericides

Weedicides (trunk injection)

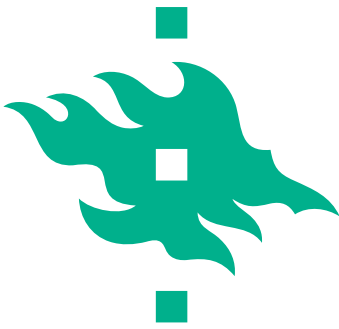
Conclusions

Based on the knowledge gained over the past several years an integrated plantation management strategy should be developed for enhancing the productivity in teak plantations

Even though research is focused on many pest species quantified data on economic impact is not available for many pests



Thanks

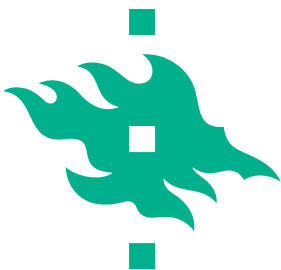


Innovations in the Management of Planted Teak Forests

31 August- 3 September 2011, Peechi, India

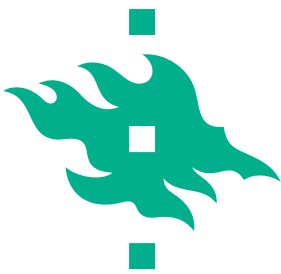
Teak plantations for climate change mitigation and ecosystem services

Professor Markku Kanninen,
Viikki Tropical Resources Institute (VITRI), University of Helsinki
Senior Associate, Center for International Forestry Research (CIFOR)



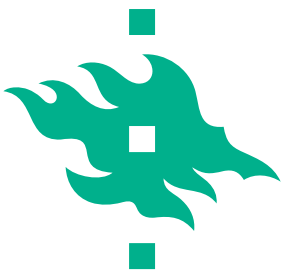
Contents

- Introduction
- Ecosystem services – Concept and applications
- Ecosystems services of plantations
 - Plantations and carbon sequestration
 - Plantations and water
 - Managing biodiversity
- Future challenges in plantation landscape management

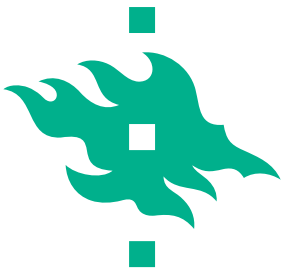


Introduction

- Increasing wood demand
 - Increasing importance of plantations
- Landscape fragmentation and degradation of natural and man-made ecosystems
 - Ecosystem restoration, forest rehabilitation
- Climate change challenges
 - Role of forests in mitigation and adaptation
- Concept of ecosystem services
 - Linking the above issues at landscape level
 - Linking global to global – humans and nature



Ecosystem services



Constanza et al. – Nature 387 (1997)

articles

The value of the world's ecosystem services and natural capital

Robert Costanza^{*,†}, Ralph d'Arge[‡], Rudolf de Groot[§], Stephen Farber^{||}, Monica Grasso[†], Bruce Hannon[¶], Karin Limburg[#], Shahid Naeem^{}, Robert V. O'Neill^{††}, Jose Paruelo^{‡‡}, Robert G. Raskin^{§§}, Paul Sutton^{|||} & Marjan van den Belt^{¶¶}**

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[‡] Economics Department (emeritus), University of Wyoming, Laramie, Wyoming 82070, USA

[§] Center for Environment and Climate Studies, Wageningen Agricultural University, PO Box 9101, 6700 HB Wageningen, The Netherlands

^{||} Graduate School of Public and International Affairs, University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA

[¶] Geography Department and NCSA, University of Illinois, Urbana, Illinois 61801, USA

[#] Institute of Ecosystem Studies, Millbrook, New York, USA

^{**} Department of Ecology, Evolution and Behavior, University of Minnesota, St Paul, Minnesota 55108, USA

^{††} Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA

^{‡‡} Department of Ecology, Faculty of Agronomy, University of Buenos Aires, Av. San Martin 4453, 1417 Buenos Aires, Argentina

^{§§} Jet Propulsion Laboratory, Pasadena, California 91109, USA

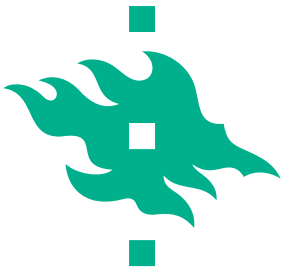
^{|||} National Center for Geographic Information and Analysis, Department of Geography, University of California at Santa Barbara, Santa Barbara, California 93106, USA

^{¶¶} Ecological Economics Research and Applications Inc., PO Box 1589, Solomons, Maryland 20688, USA

The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet. We have estimated the current economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US\$16–54 trillion (10¹²) per year, with an average of US\$33 trillion per year. Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US\$18 trillion per year.

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1.9.2015

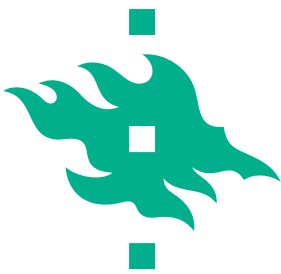


Ecosystem Services - definition

The Millennium Ecosystem Assessment (2003) defines ecosystem services as the **benefits people obtain from ecosystems**

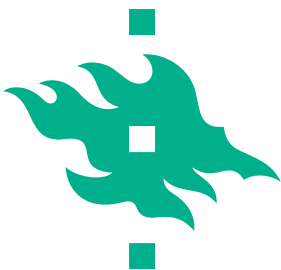
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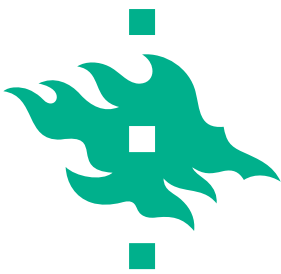
Ecosystem services: why?

- Ecosystem services are essential to the survival of human beings
- Ecosystems operate and provide services on such a grand scale and in such ways that most of them cannot effectively be replaced by technology

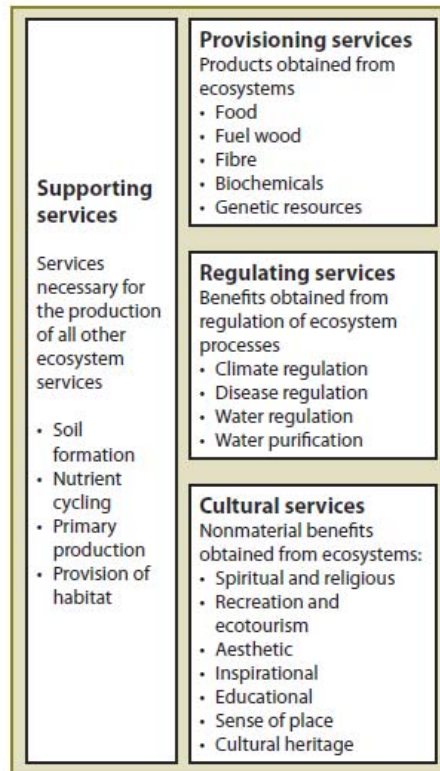


Ecosystem services: why?

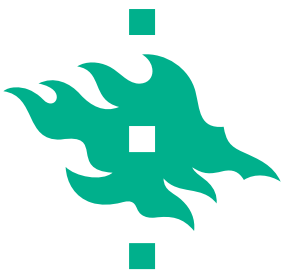
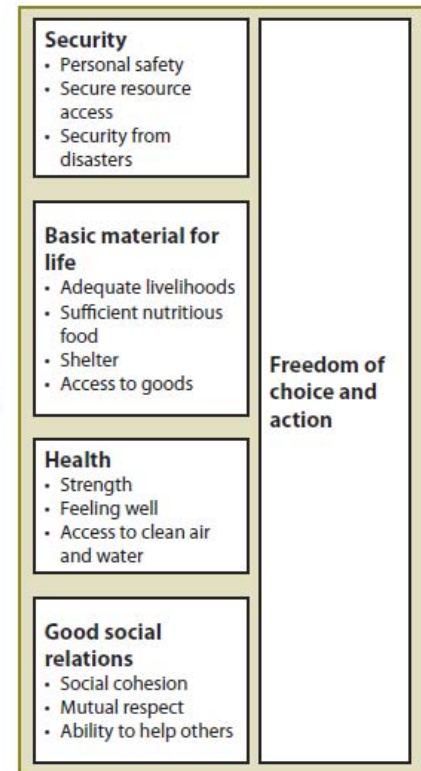
- Human activities are already impairing the flow of ecosystem services from forests on a large scale
- If current trends continue, human activities will dramatically alter a large share of the Earth's remaining natural forest ecosystems within a few decades, especially in the tropics



Ecosystem Services



Constituents of Wellbeing



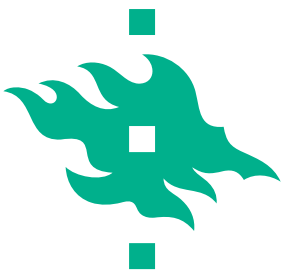
Ecosystem services and human well-being

Three types of services contribute directly to human well-being

- **Provisioning services** (also called ecosystem goods), such as timber, food, fodder, and fuel wood
- **Regulating services**, such as regulation of water, climate and erosion
- **Cultural services**, such as recreational, spiritual and religious services

Fourth type of services is necessary for the production of other services

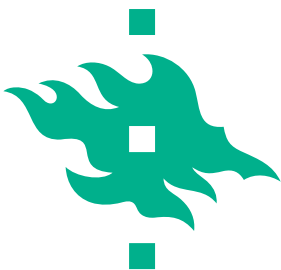
- **Supporting services**, such as primary production, biodiversity, nutrient cycling and soil formation



Provisioning services

Ecosystems produce diverse goods for local people

- Wood is an important economic forest commodity for many tropical countries
- Fuel wood meets about 15% of energy demand in developing countries - more than 80% in Africa
- Non-wood forest products are extremely diverse, from fodder for animals and food for people to medicines and cosmetics
 - The livelihoods of 250 million to 1 billion people depend on these products
 - Edible forest products include bushmeat, fish and plants
 - Traditional medicines and the development of modern medicines



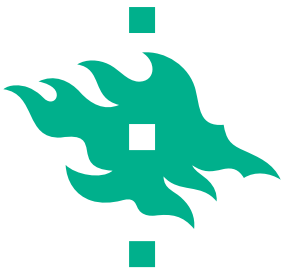
Regulating services

Ecosystems provide global services

- They regulate the global climate and store carbon

They also provide local or regional services

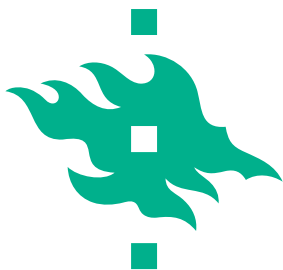
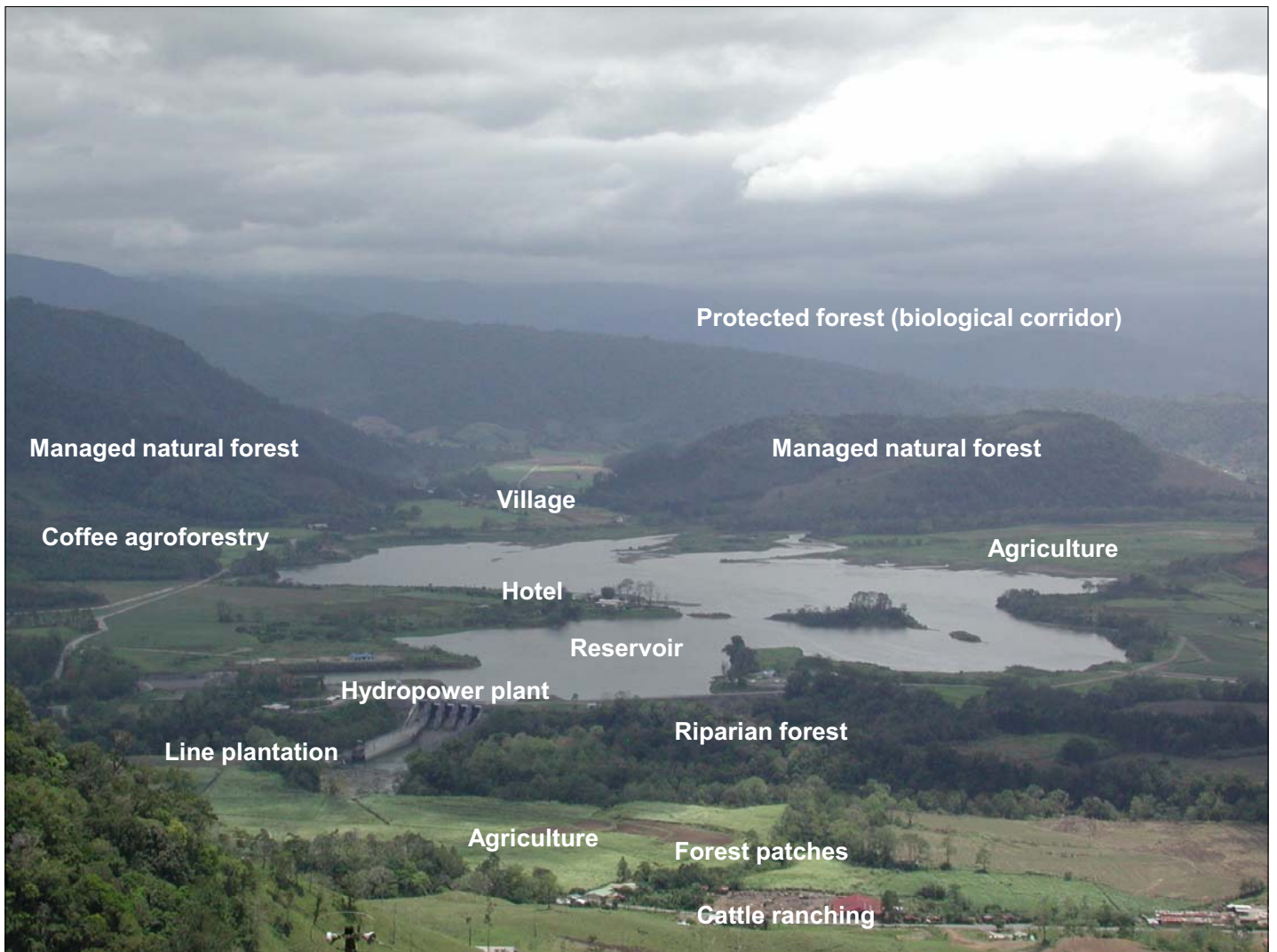
- Purification of water, mitigation of floods and drought, detoxification and decomposition of wastes, generation and renewal of soil
- Pollination of crops and natural vegetation, control of agricultural pests, dispersal of seeds, and moderation of temperature extremes and the force of winds and waves



Cultural services

- For many local communities, ecosystems have spiritual and religious value
- Ecosystem changes can affect cultural identity and social stability
- Other services, such as aesthetic, recreation and heritage, are enjoyed by local people, visitors and those for whom the ecosystem has a symbolic importance

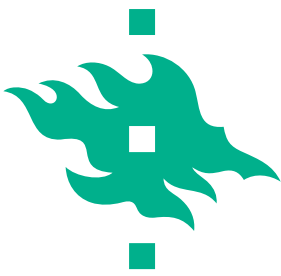




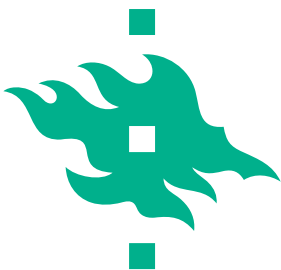
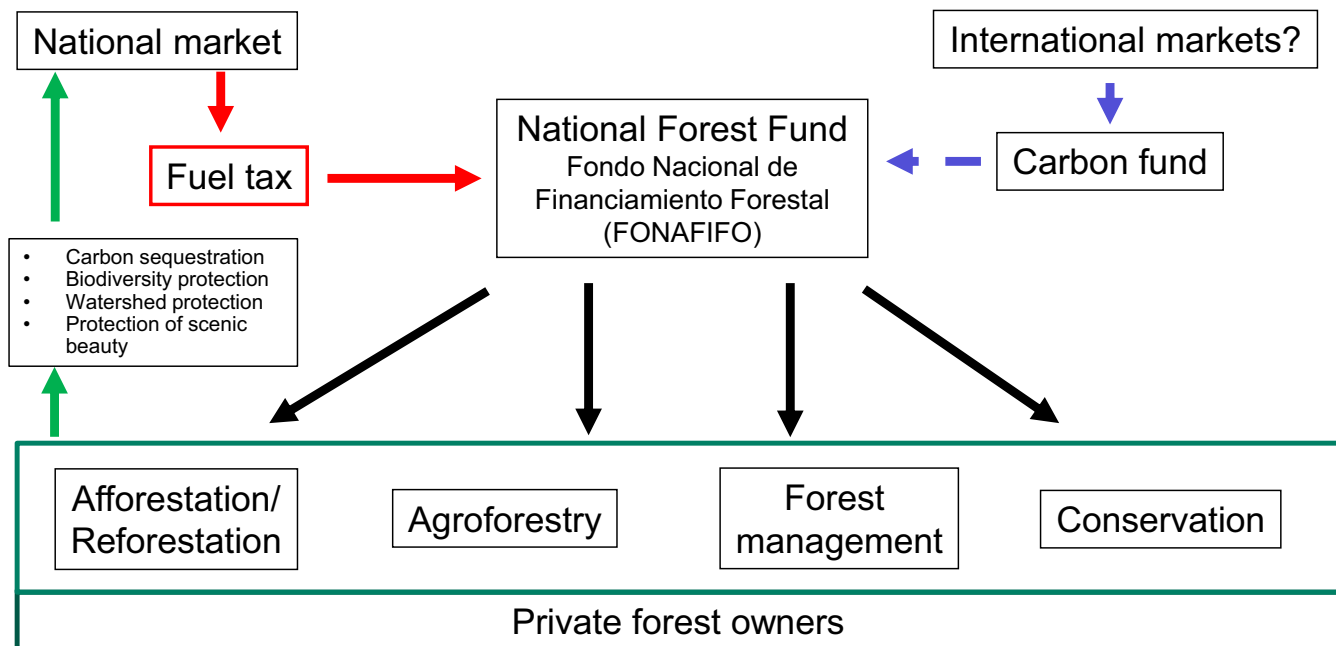
Costa Rica - Payments for ecosystem services

- The 1996 forestry law acknowledges four types of ecosystem services of forests:
 - Carbon sequestration
 - Biodiversity protection
 - Watershed protection
 - Protection of scenic beauty
- Lump sum per hectare payment for simplicity of implementation





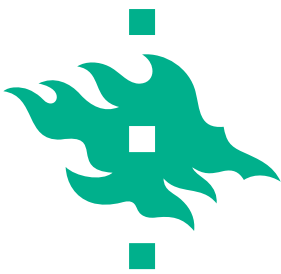
Costa Rica - Payment for environmental services



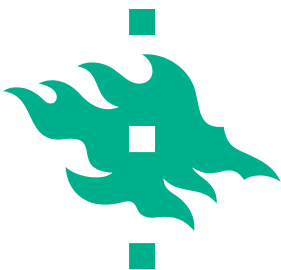
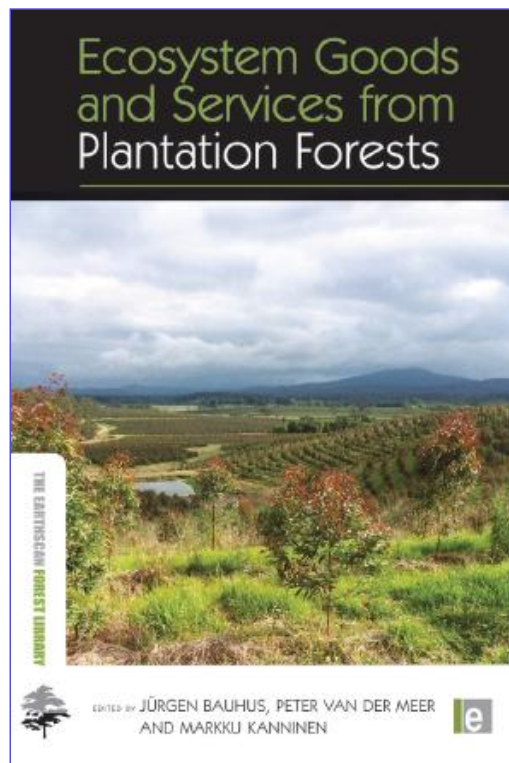
Vulnerability of ecosystem services

Ecosystems are threatened by various human-induced pressures

- These pressures include land use change, landscape fragmentation, degradation of habitats, over-extraction of resources, pollution, nitrogen deposition and invasive species
- Climate change will increase these pressures over the coming decades
 - -> Ecosystem-based adaptation to climate change
 - -> Role of forests in climate change mitigation

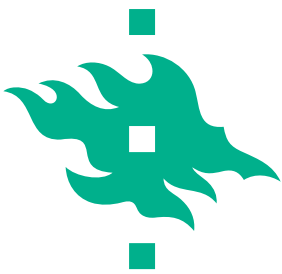


Ecosystem services from plantations



Ecosystem services from plantations

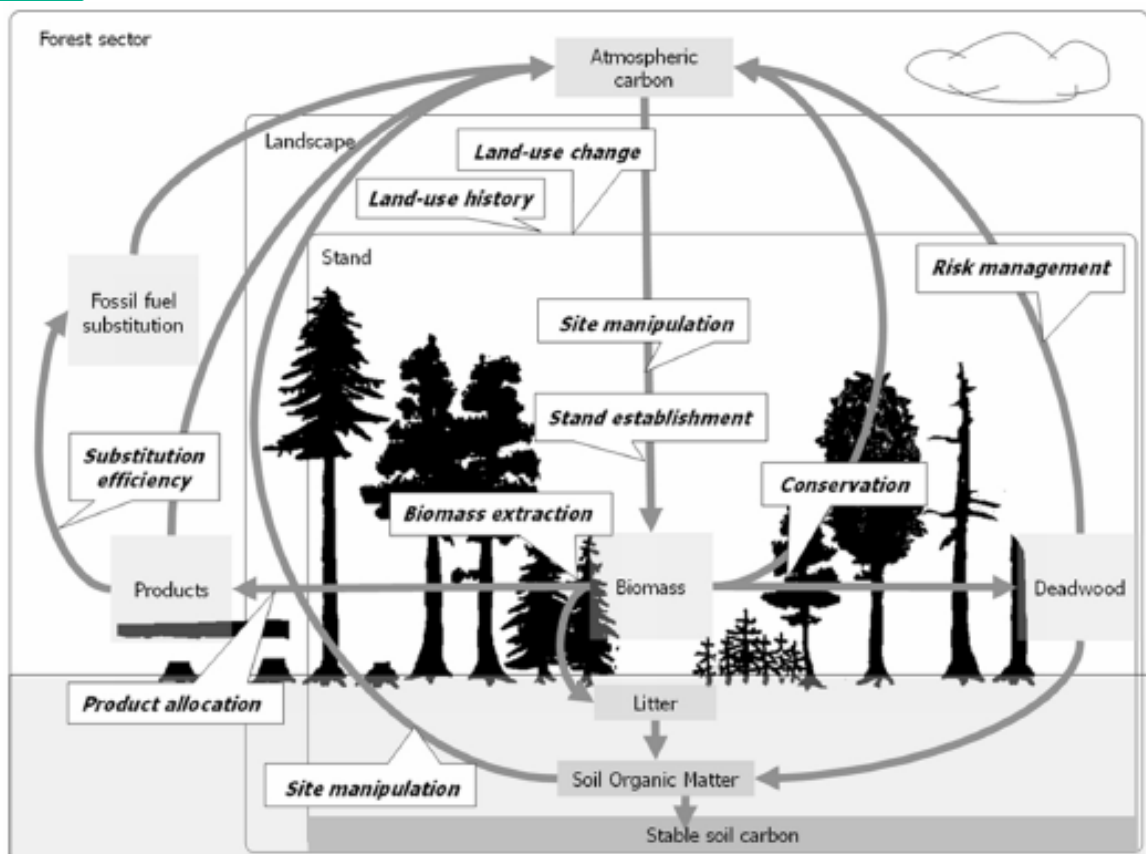
- Carbon sequestration
 - UNFCCC & Kyoto Protocol – CDM's (A&R)
 - Other mechanisms
 - Linking mitigation & adaptation
- Water
 - Water flow regulation – reducing vulnerability
 - Water quality for human use
- Biodiversity
 - Role of planted trees and forests in fragmented landscape mosaics
 - Corridors and connectivity in landscapes
- Other
 - Food & other links with agriculture
 - Pollination, disease and pest control

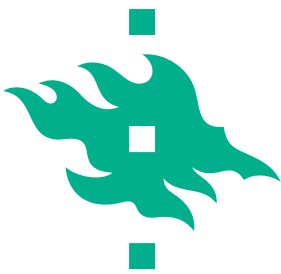


Carbon sequestration

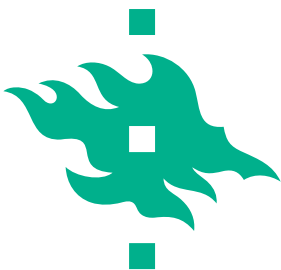
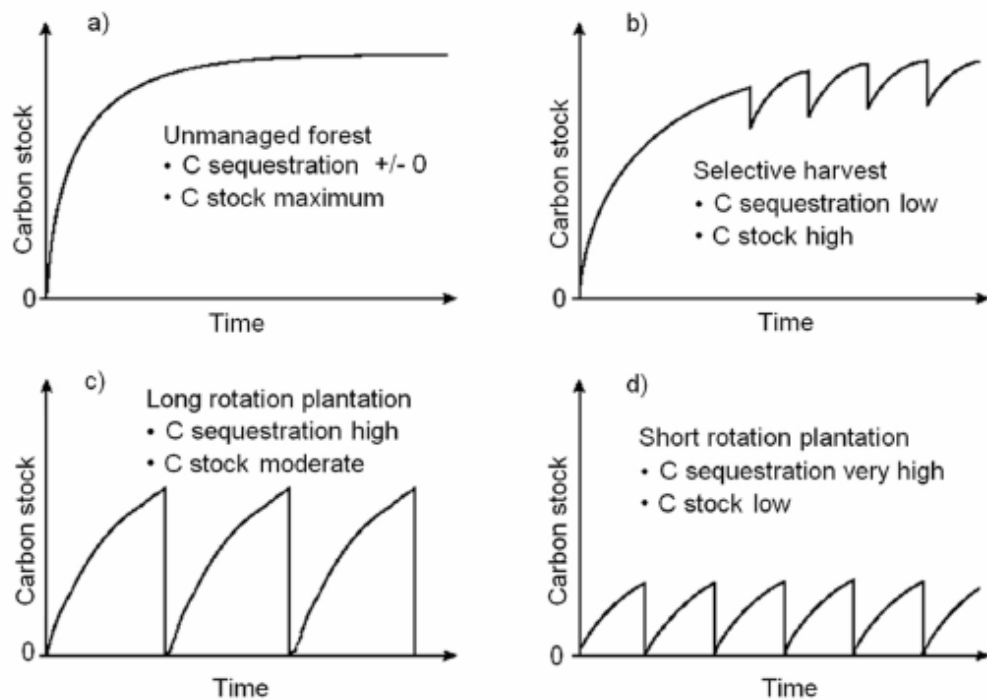


Forest management options for mitigation





Carbon stock in different management systems



CO2FIX – Stand-level carbon simulator

Available at <http://www.efi.fi/projects/casfor/>



ELSEVIER

Ecological Modelling 164 (2003) 177–199

ECOLOGICAL
MODELLING

www.elsevier.com/locate/ecolmodel

Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach

Omar R. Masera^{a,*}, J.F. Garza-Caligaris^a, M. Kanninen^{b,1}, T. Karjalainen^g,
J. Liski^{c,2}, G.J. Nabuurs^d, A. Pussinen^c, B.H.J. de Jong^e, G.M.J. Mohren^f

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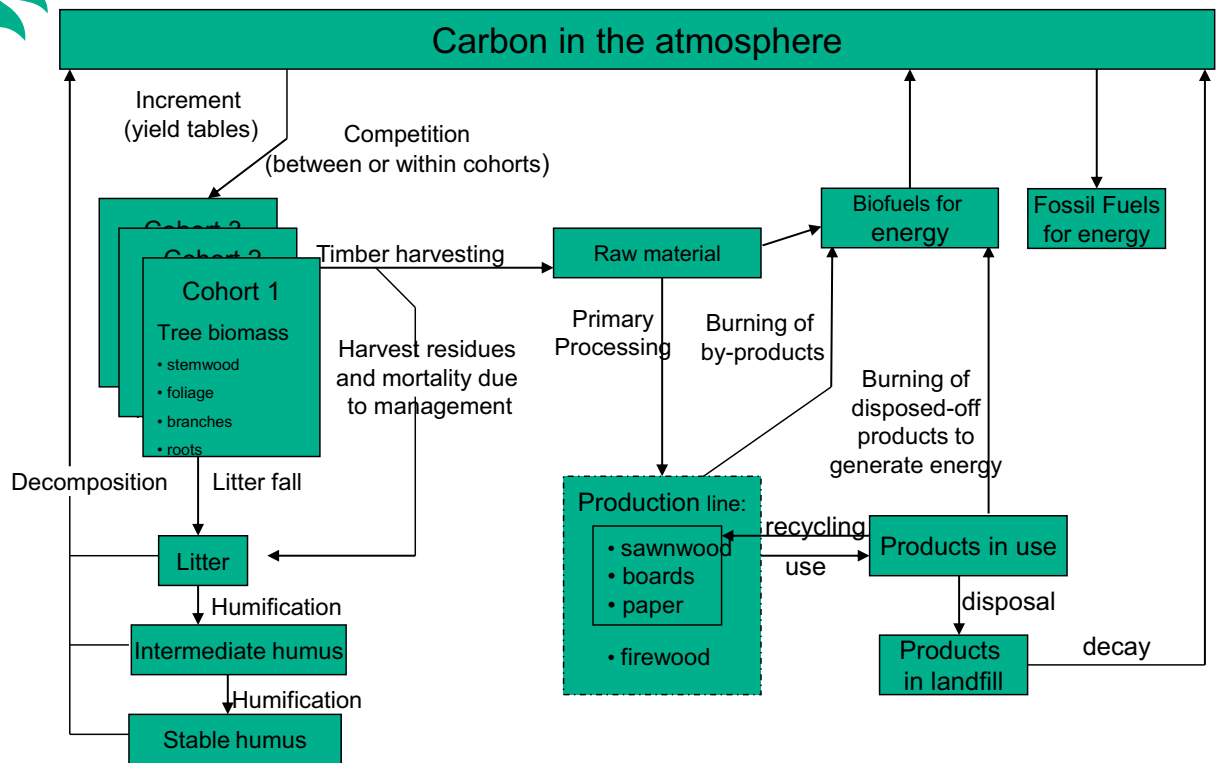
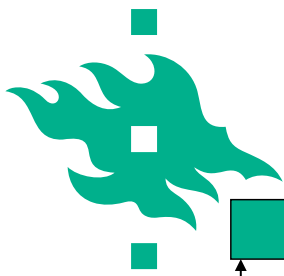
^e El Colegio de la Frontera Sur, Apdo. Postal 1042, C.P. 86100, Admin. de Correos 2, Col Atasta, Villahermosa, Tab, Mexico

^f Forest Ecology and Forest Management Group, Department of Environmental Sciences, Wageningen University, P.O. Box 342, 6700 AH Wageningen, The Netherlands

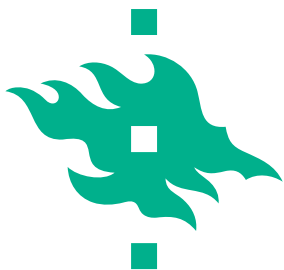
^g Finnish Forest Research Institute, P.O. Box 68, FIN 80101 Joensuu, Finland

Received 22 January 2002; received in revised form 5 November 2002; accepted 2 December 2002

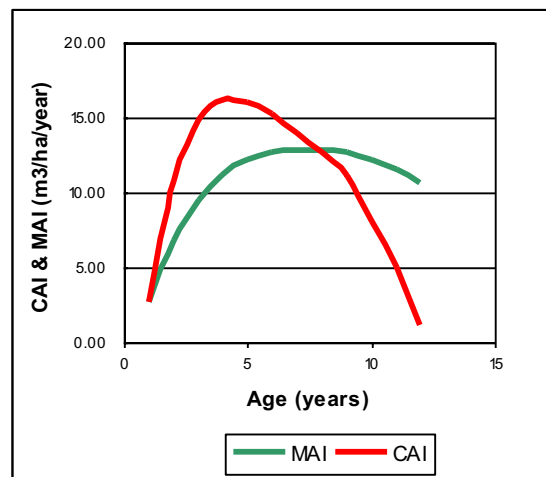
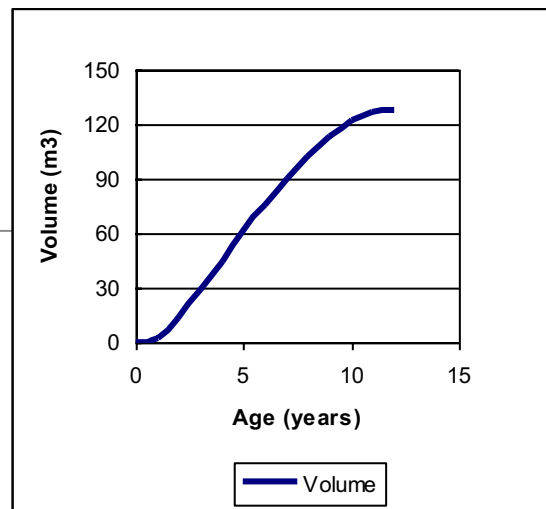
CO2FIX: model structure



Yield tables

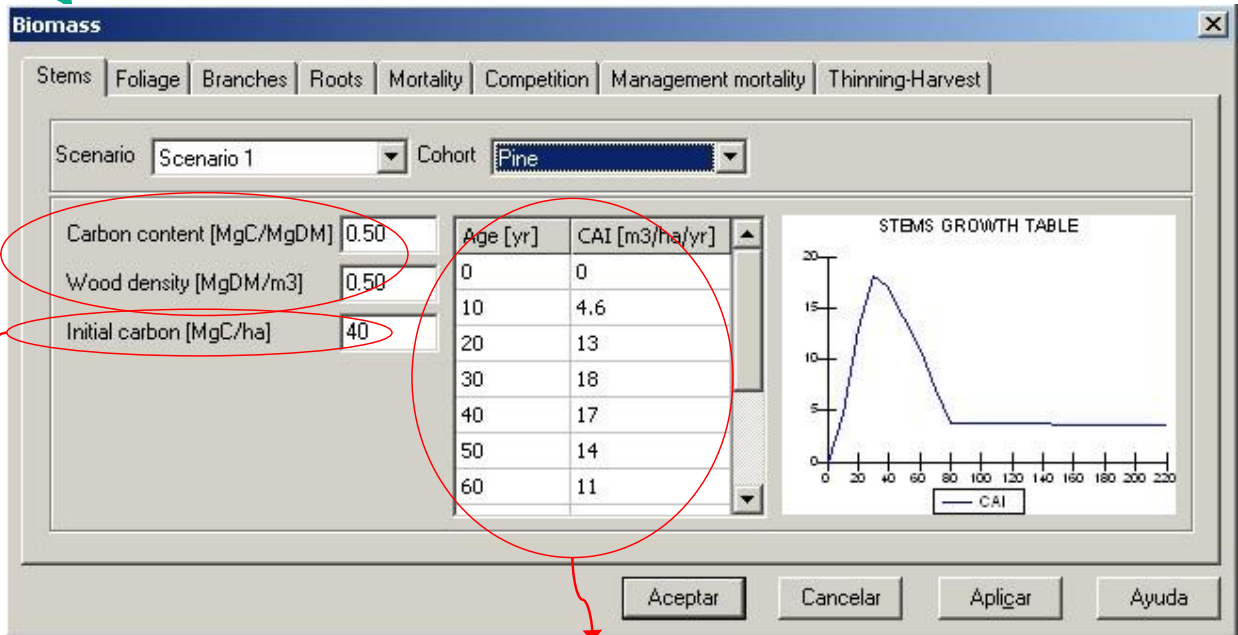


Age	Volume	MAI	CAI
0	0		
1	2.7	2.70	2.7
2	13.5	6.75	10.8
3	28.4	9.47	14.9
4	44.6	11.15	16.2
5	60.6	12.12	16
6	75.8	12.63	15.2
7	89.8	12.83	14
8	102.5	12.81	12.7
9	113.7	12.63	11.2
10	121.8	12.18	8.1
11	126.8	11.53	5
12	128	10.67	1.2





Parameterization of tree growth in CO2FIX

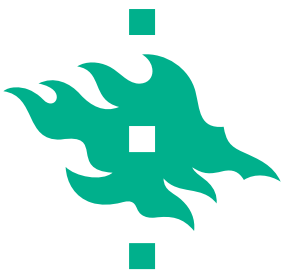


Inventory/field assessment

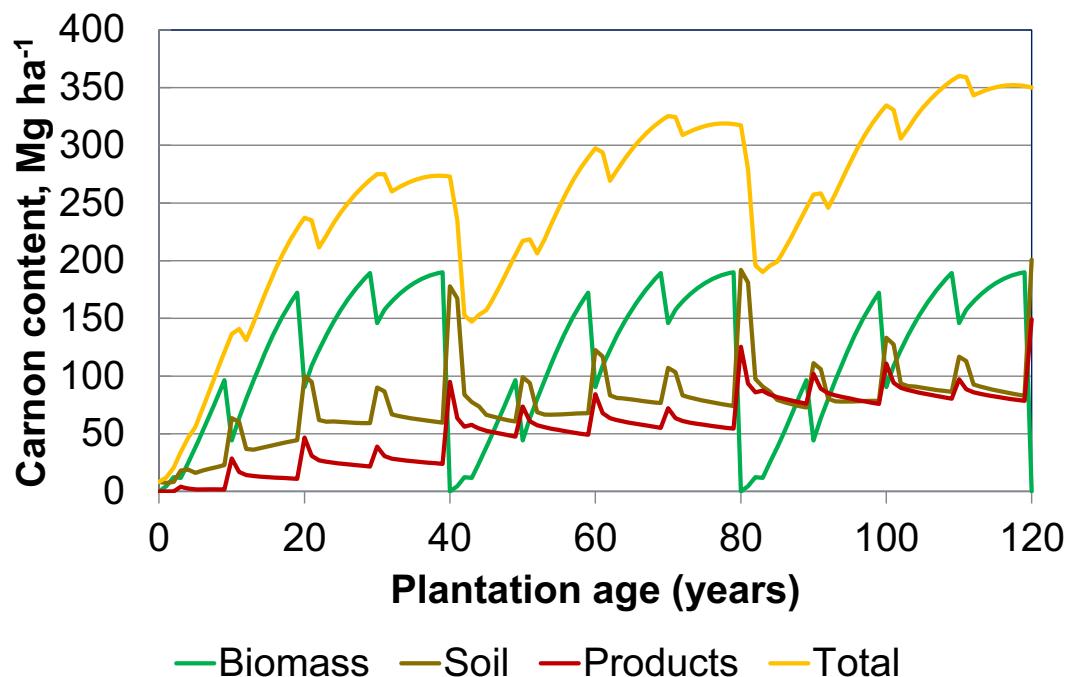
Literature/laboratory

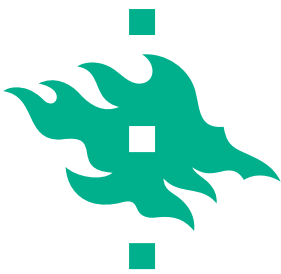
Growth data from:

- literature
- inventory
- estimation

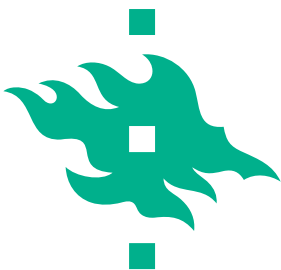


Carbon dynamics in a teak plantation (data from Costa Rica)





Water



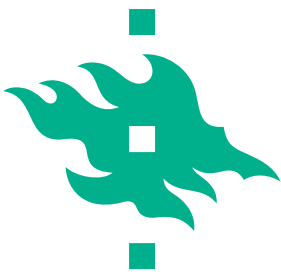
Hydrological functions (Regulation of water quantity and quality)

Value

Maintenance of hydrological cycles and fresh water quality

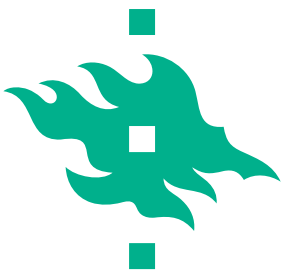
Role of plantations: Increasing infiltration rates (degraded soils)

- Buffering run-off
- Reducing soil erosion and sediment yield
- Reducing ground water pollution
- Controlling water table

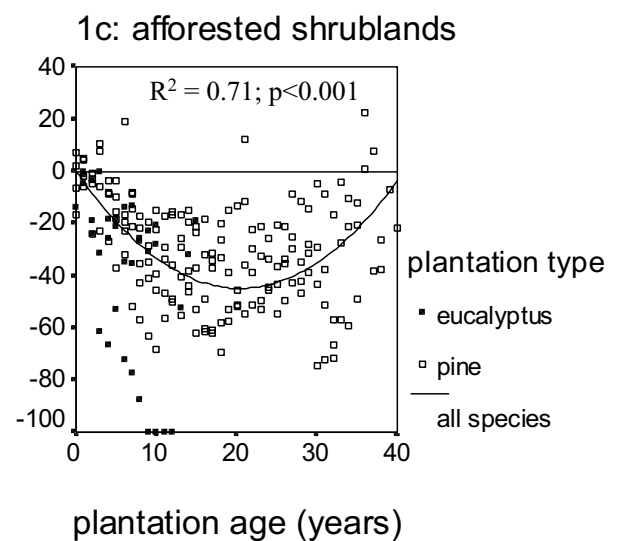
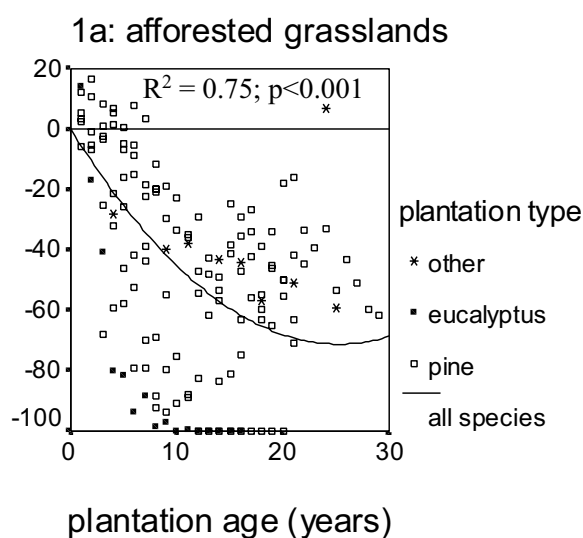


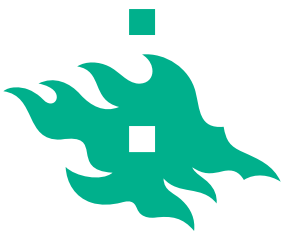
Global study on runoff in plantations (Farley et al 2005)

- Runoff reductions >75% for at least one year in 1/5 of catchments
- Runoff reductions, averaged across all plantation ages, were greater in former grasslands ($44 \pm 3\%$) than in former shrublands ($31 \pm 2\%$) ($p < 0.001$)
- Eucalypts had greater effect on runoff than pines in sites that were originally grasslands ($75 \pm 10\%$ vs $40 \pm 3\%$) ($p < 0.001$)

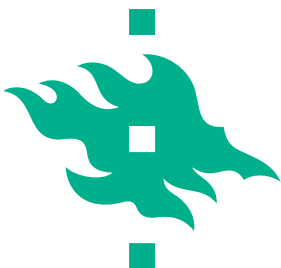
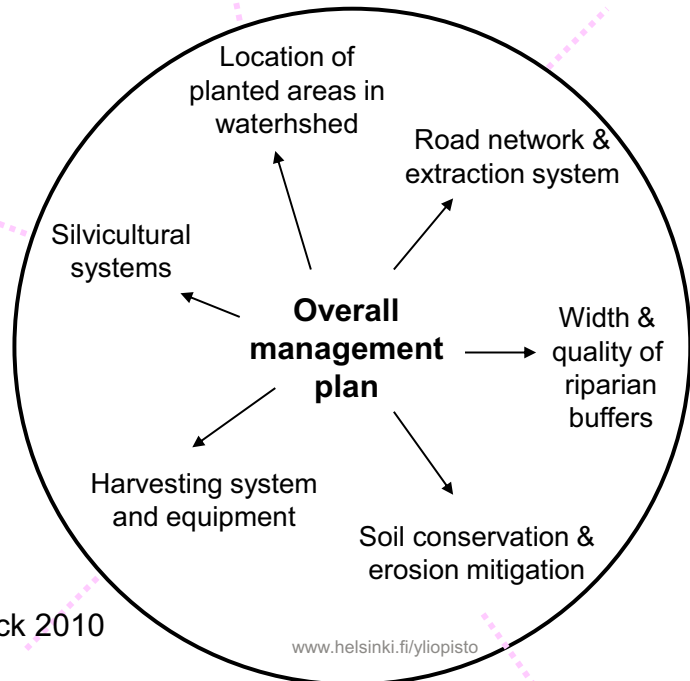
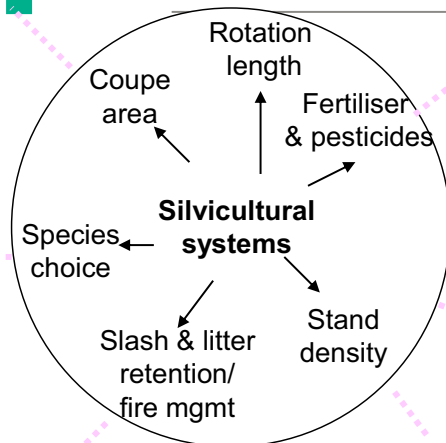


Change in runoff with plantation age



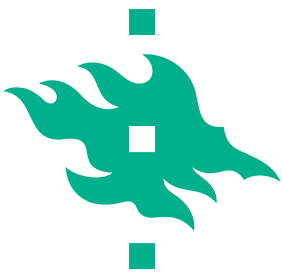


Multiscaled water management plans for forest plantations



Silvicultural measures to improve hydrological functions of plantations

- Increasing rotation length
 - Reduces average transpiration, development of forest floor and understorey, less frequent disturbance
- Use of water efficient species or species with low water use
- Conservation of forest floor and understorey
 - e.g. avoid litter removal, fire and grazing; optimize mgmt of competing vegetation
- Conservative site preparation measures
 - Contour ploughing, terracing, slash and litter retention, avoidance of soil compaction and disturbance
- Optimal use of fertilizer and pesticides



Biodiversity

Value:

The maintenance of viable populations of native flora and fauna in the landscape

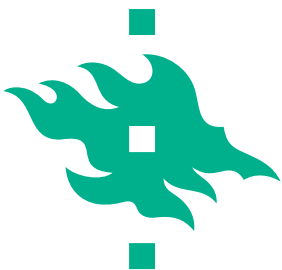
Role of plantations:

- Provision of habitat or habitat components
- Corridor functions/connectivity
- Buffering of native ecosystems

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Photo: Aracruz



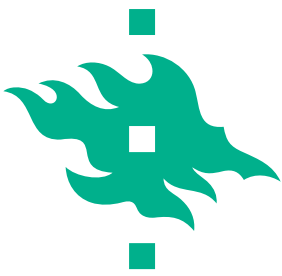
Biodiversity management

- Rehabilitation of degraded lands
- Forest and landscape restoration

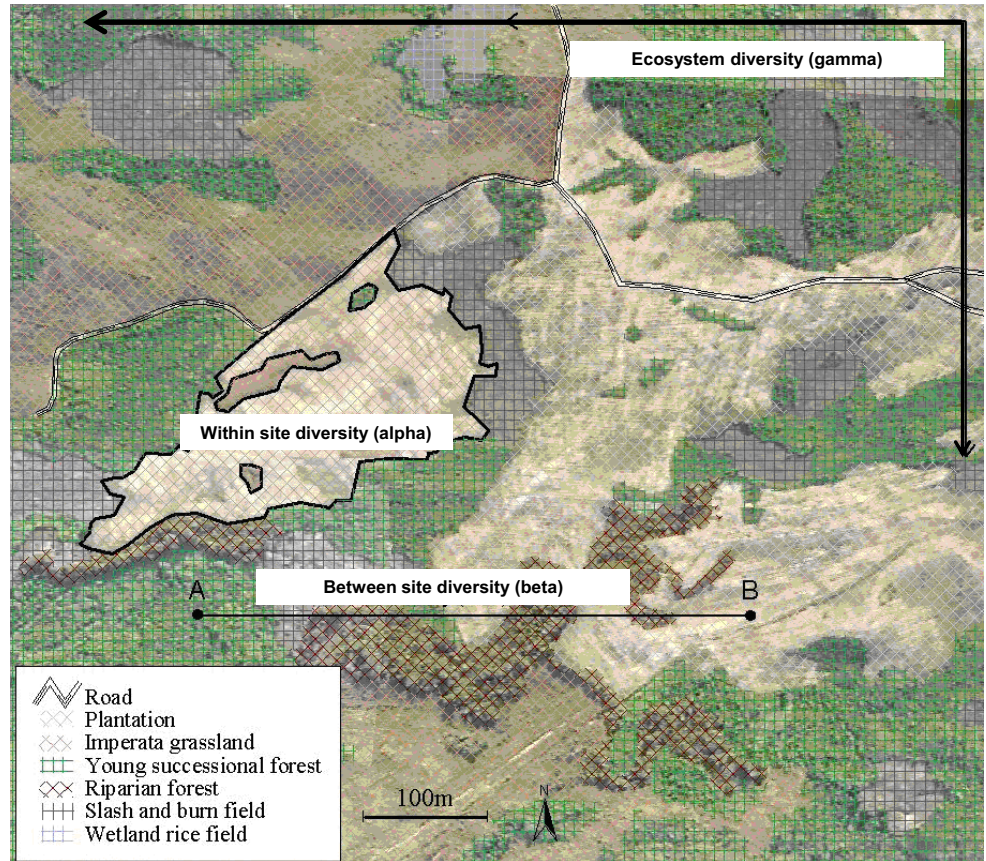
Direct impacts in landscapes

- Landscape level
 - Connectivity, riparian forests
- Stand level
 - Increased structural complexity
 - Species mixtures
 - Prolonged rotations
 - Alternative methods of site preparation

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Plantation landscape in Kalimantan



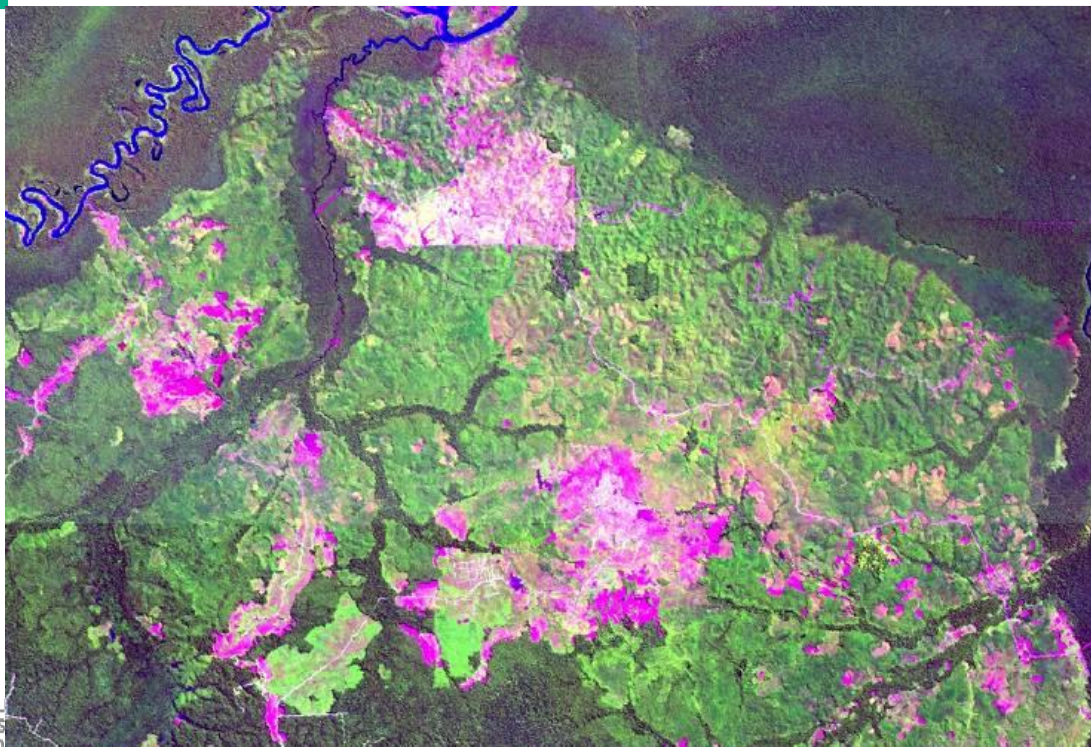
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Marjokorpi 2006

1.9.2037



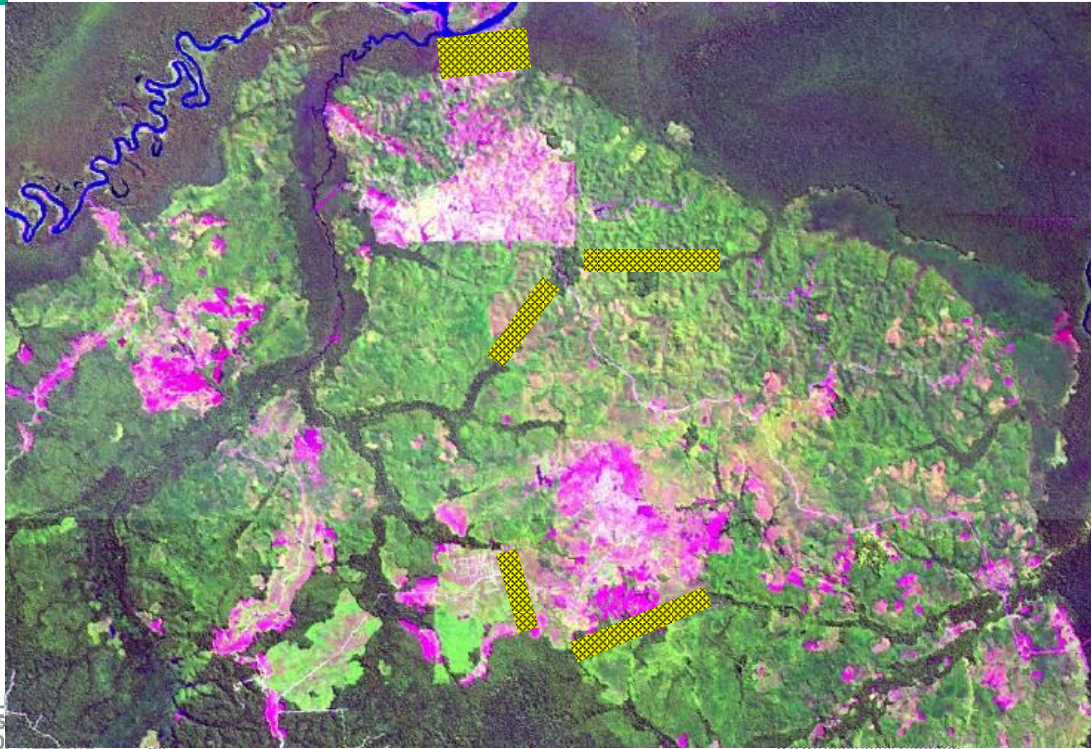
Connectivity in plantation landscapes



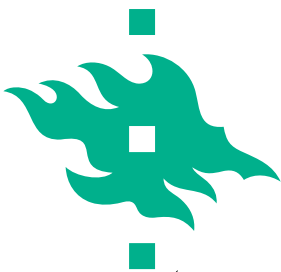
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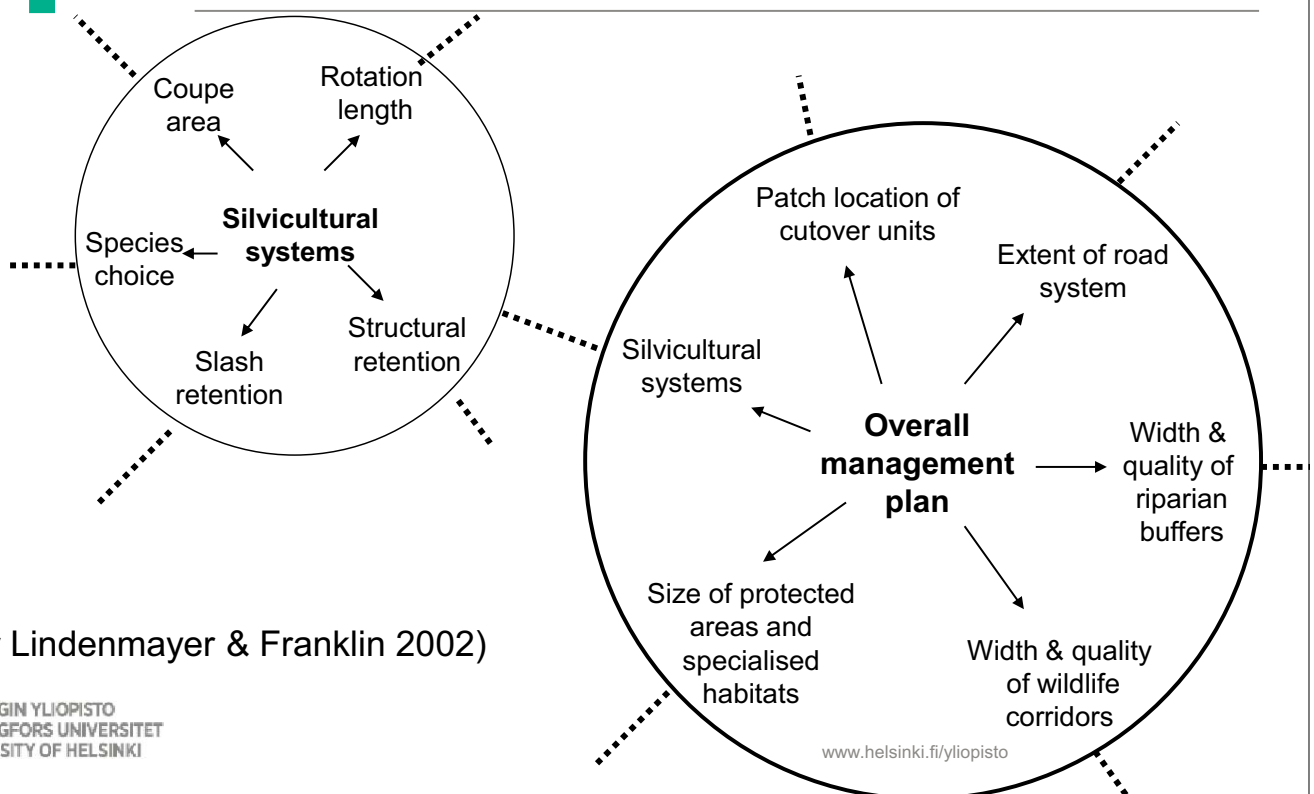
Connectivity in plantation landscapes

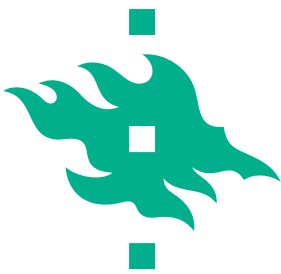


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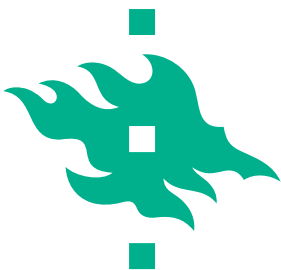


Multiscaled plans for forest biodiversity conservation



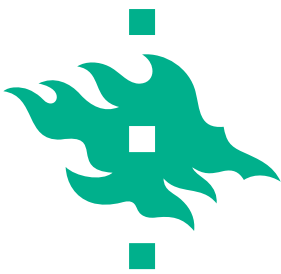


Future challenges in plantation landscape management

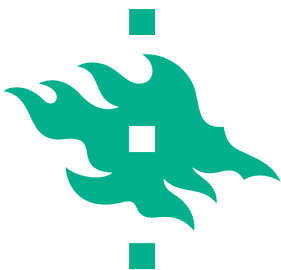
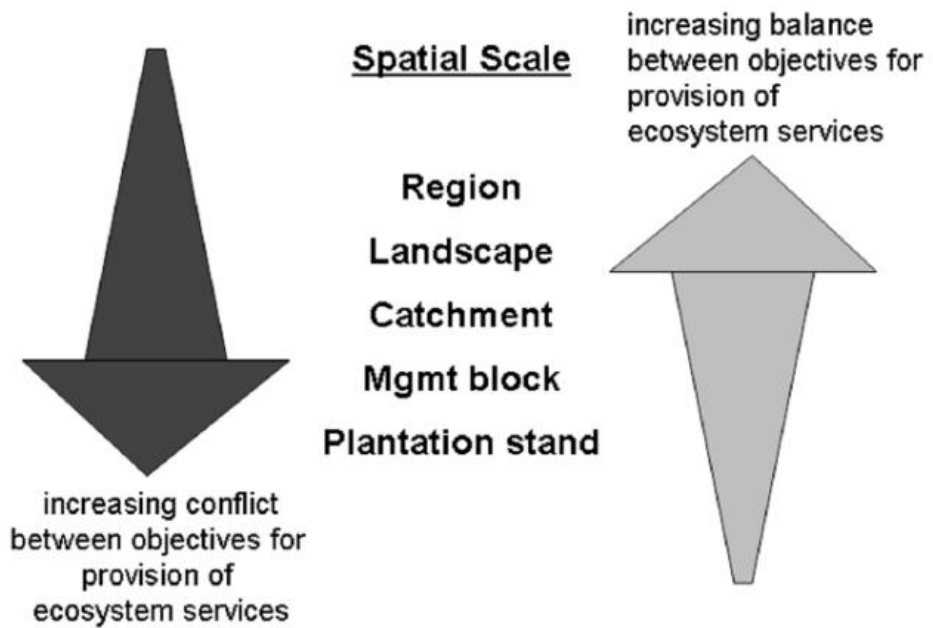


Trade-offs and synergies

- There is no form of plantation management that can provide a maximum of all ecosystems goods and services to all stakeholder groups
 - -> trade-offs, conflicts, synergies
- **Some of the services conflict with each other**
- It would **not be possible** to try to maximize wood production, carbon sequestration, conservation of biodiversity, and social and cultural benefits values in the same plantation stand
- With increasing spatial scale, that is moving from one plantation stand or one property, to the watershed or landscape, it becomes **increasingly easier to reconcile** conflicting or non-complementary objectives of management



Scale matters



Scales vs. environmental services

Question: Does the scale matter?

Answer: It depends

Biodiversity: prevent habitat loss

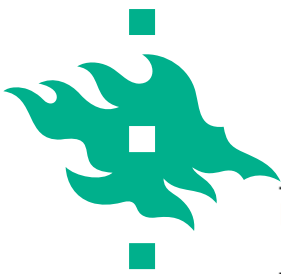
- Landscapes, connectivity, climate change

Carbon: increase C content in the biosphere, prevent emissions

- Any scale, management

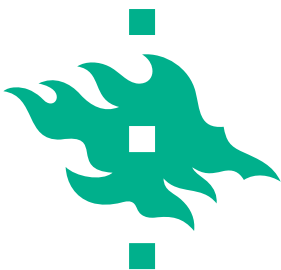
Water: clean water for human use

- Landscapes, management, species, climate change

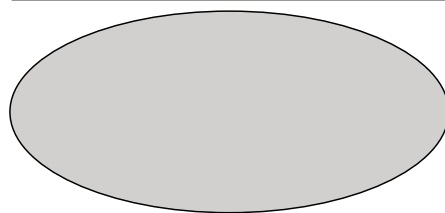


Trade-offs between management options

Management options	Plantation productivity	Biodiversity	Carbon*	Water*	Amenity values
Stand level					
Structural retention	-	+	?	+	+
Use of native species	-	+	(-)	(+)	+
Mixed-species stands	+	+	+	-	+
Long rotations	-	+	?	+	+
Thinning	0	+	-	+	(+)
Site preparation	+	-	?	?	-
Herbicides and fertiliser	+	-	?	-	-
Landscape level					
Riparian buffers (of native vegetation)	-	+	(+)	+	+
Retaining patches of native vegetation	-	+	(+)	+	+
Connectivity between plantations and native forests	0	+	0	0	+
Maintaining landscape heterogeneity (different land use types, special places, etc.)	-	+	?	+	+

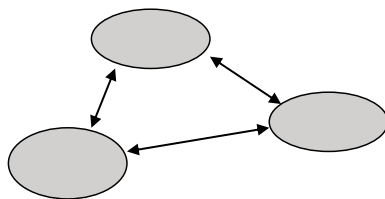


Planning levels for plantation landscape management



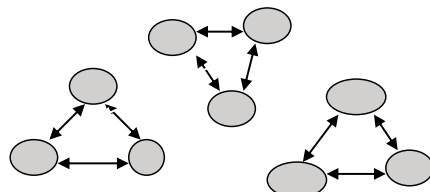
LANDSCAPE

Ecosystem Management



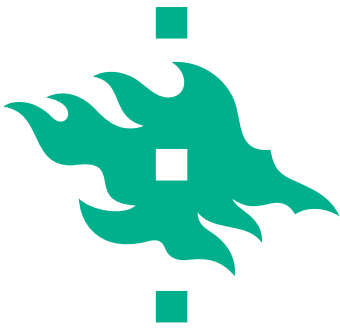
ESTATE/COMPANY

Resource Management



STAND LEVEL

Silviculture



**Thank you for your
attention**

markku.kanninen@helsinki.fi

Teak farms – a strategy for growth and job creation in rural Asia

Presented by: Dede Rohadi

Center for Research and Development on Climate Change and Forests Policy
Forestry Research and Development Agency
Ministry of Forestry of Indonesia

International Training Program
Innovations in the Management of Planted Forests

Kerala Forest Research Institute
Peechi Campus, India

31 August – 3 September 2011

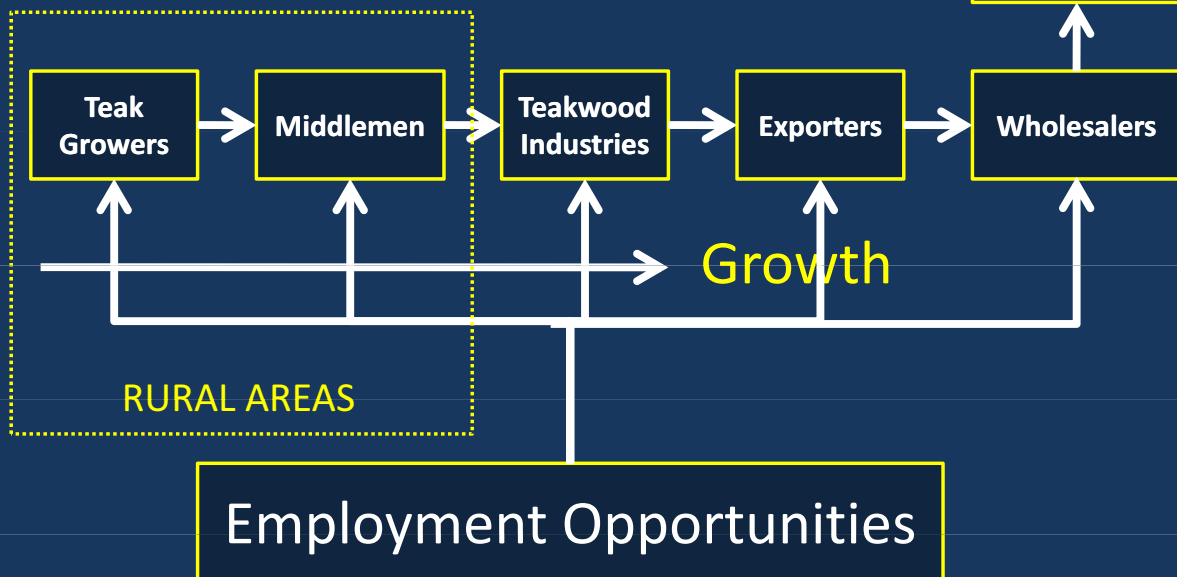


Outline of presentation

1. Introduction
2. Teak farms in Gunungkidul District
3. Teak farms in household economic structure
4. Challenges for improving economic outcomes for smallholder teak growers
5. Strategy options for improving the economic benefits of teak farms

Introduction

The context:



Introduction

Why Teak ?

- One among the most valuable timber species (quality, uses, market, price).
- High demand
- Involves millions of teak farmers in rural areas and millions workers in teak wood industries.
- Has long history of plantation (part of farmer's culture).

Introduction

CIFOR study on teak in Gunungkidul:

- ACIAR funded project (*Improving Economic Outcomes for Smallholders Growing Teak in Agroforestry System in Indonesia/FST/2005/177*).
- Action research (July 2007-June 2011)
- Three main objectives:
 - ✓ Introduce and adapt silviculture techniques to improve productivity and quality of smallholder teak farms,
 - ✓ Develop suitable micro-credit scheme for teak growers,
 - ✓ Develop teak marketing strategies for better return to teak growers.

Teak farms in Gunungkidul District

1. In 1950s, Gunungkidul district is among the most degraded areas in Indonesia.
2. Teak farms started to develop during the mid 1960s.
3. Forest cover increased from 3%(1950s) to 29% (2010). About 70% of the forest consists of teak farms.
4. Types of smallholder teak plantations:
 - Kitren = Woodlot dominated by teak
 - Tegalan = Teak-based agroforestry system
 - Homegarden = Teak and fruit trees
 - Sawah = paddy fields

Teak farms in Gunungkidul District



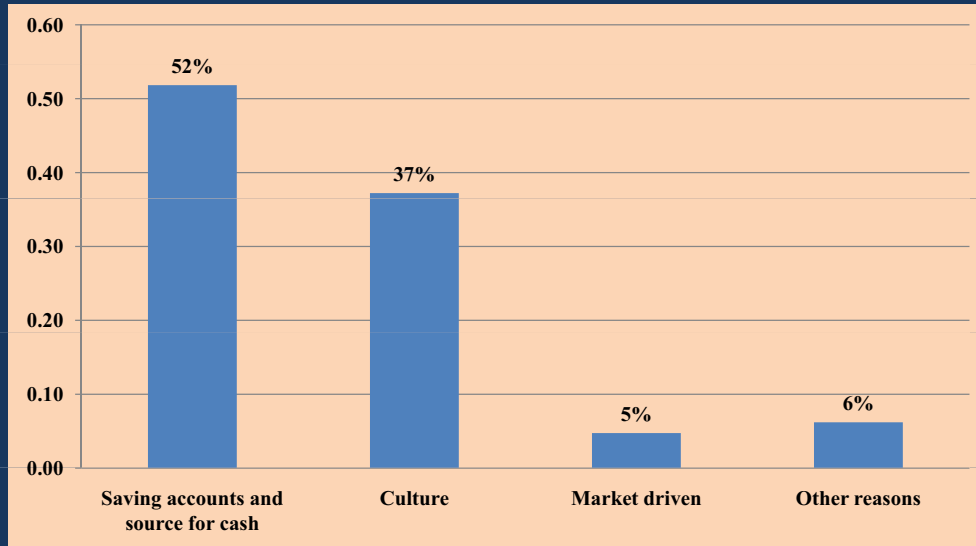
Teak farms in household economic structure

Teak-based farming system

Land use system	% from the total parcels measured	Average size of parcels (ha)	Average number of tree species planted	Average number of trees per ha
Tegalan	53.9	0.32	8	1,072
Pekarangan	23.8	0.16	13	1,177
Kitren	9.1	0.24	5	1,532
Sawah	8.5	0.24	7	138

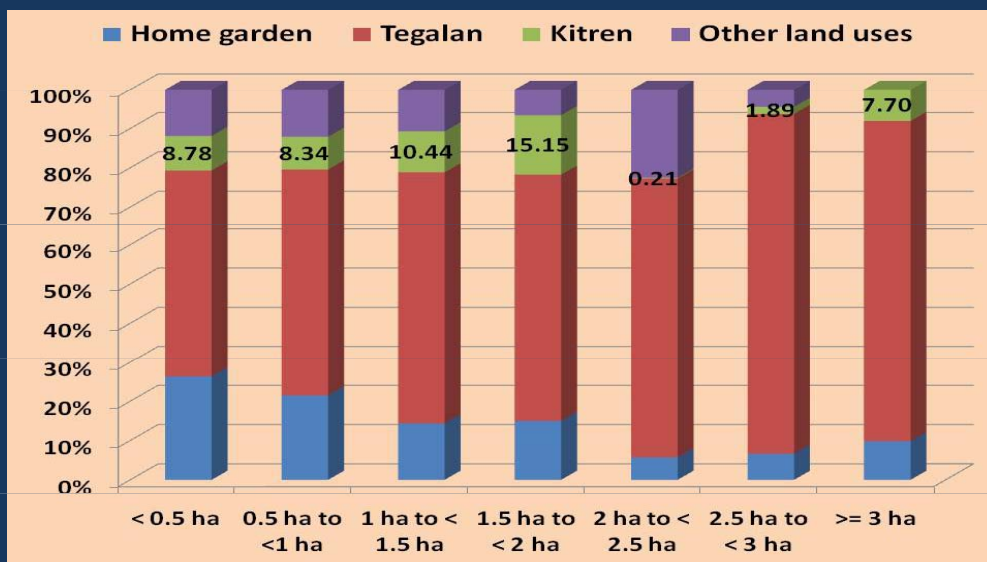
Teak farms in household economic structure

Farmers' perceptions for planting teak



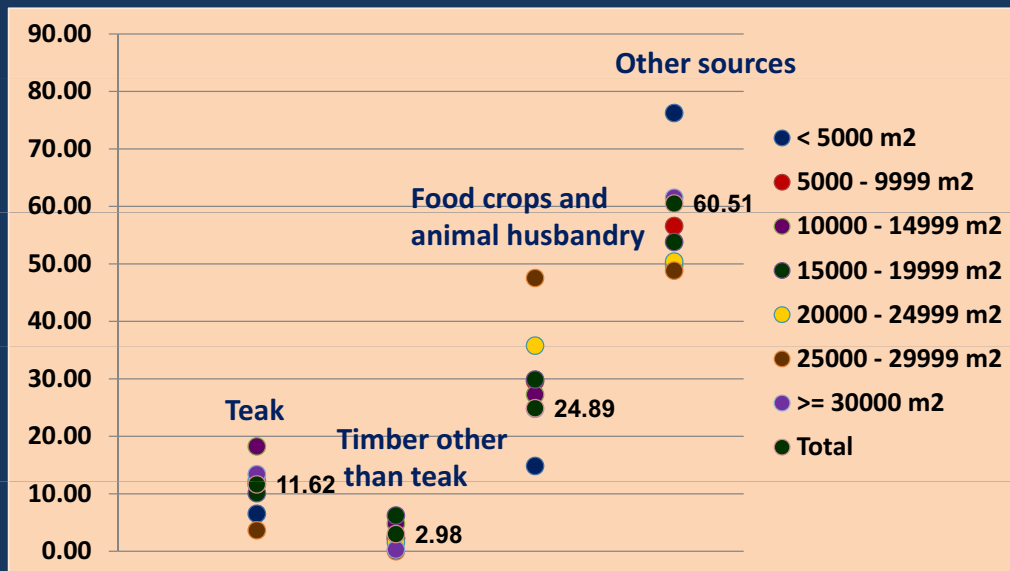
Teak farms in household economic structure

Land use allocation



Teak farms in household economic structure

Household income structure



Challenges for improving economic outcomes for smallholder teak growers

Low financial benefits of smallholder teak plantations

No.	Types of plantation	Cost of establishment		Maintenance cost until the first harvest		Potential income per month		Net Present Value		B/C ratio
		million Rp	US\$	million Rp	US\$	million Rp	US\$	million Rp	US\$	
1	Kitren system	3.51	369	1.03	108	0.83	88	15.07	1,586	2.35
2	Tegalan system:									
	- Respondent 1	1.67	176	1.58	166	0.44	47	44.62	4,697	4.31
	- Respondent 2	14.71	1,549	14.59	1,536	0.73	76	73.05	7,690	1.59
	- Respondent 3	5.14	541	4.99	525	2.18	230	220.43	23,203	6.21
	- Respondent 4	23.68	2,493	23.53	2,477	4.89	515	494.07	52,008	3.49
	- Respondent 5	7.97	839	7.87	828	1.45	153	185.40	19,516	3.20

Challenges for improving economic outcomes for smallholder teak growers

Poor silviculture practices!

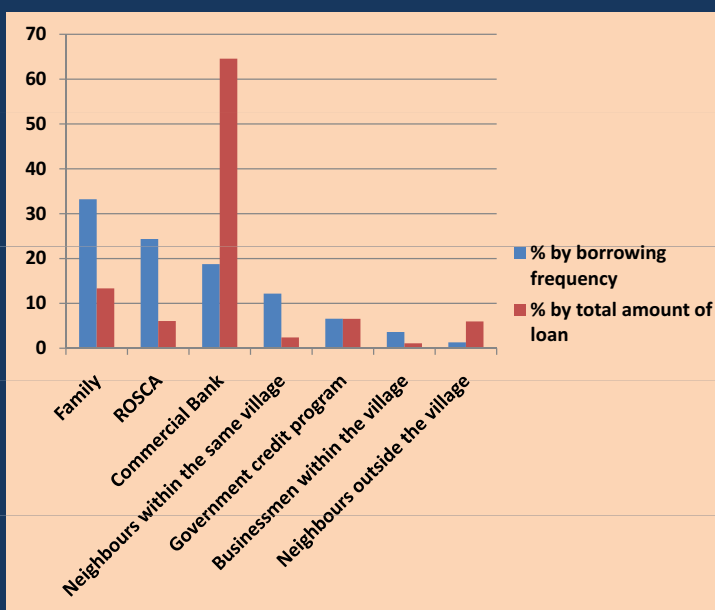
- Regeneration:
 - 72% wildlings,
 - 30% local seedling,
 - 20% coppice,
 - 12% improved seedlings
- Pruning: in reality is collecting fuelwood, leaving 10-15 cm stub
- Thinning: 57% thinning (but in actual is harvesting/priming)
- Coppice: no thinning
- **No management to improve production /growth.**



Poor silviculture practices of farmers' teak systems lead to overstock, slow growing, low quality, low productivity

Challenges for improving economic outcomes for smallholder teak growers

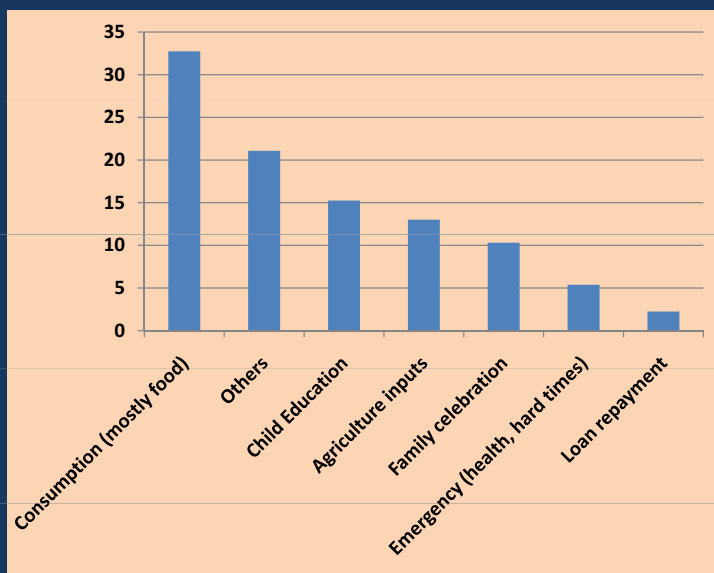
Lack of farmers access to loan



- Less than 20% of farmers have access of loans to commercial bank.
- Family and ROSCA are the most sources of loans.
- Limited government credit program available, both in access and amount of money.

Challenges for improving economic outcomes for smallholder teak growers

Lack of farmers access to loan



- Most of the loans were used for daily consumption, not related with investment on farm activities.

Challenges for improving economic outcomes for smallholder teak growers

Marketing problems

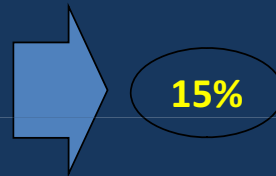
- Most farmers sell trees, not log
- Lack on market information (log quality standard and prices)
- Low bargaining power
- High transaction costs, due to:
 - Dispersed and small amount of trees for sale
 - Poor quality of trees
 - Timber transport documents

An Ilustrasi of marketing margin by middlemen

Operational costs

Cost items	Volume	Total cost (Rupiah)
Felling permit	1 transaction	20,000
Timber transport document	1 transaction	230,000
Felling operator	1 person	40,000
Chain saw rent	1 unit	180,000
Log hauling	7 person	210,000
Log hauling at logyard	1 packaget	100,000
Total		780,000

Farmgate price :	Rp 975.000
Operational costs :	Rp 780.000
Log selling price :	Rp 2.016.981
Profit margin :	Rp 261.981



17

Strategy options for improving the economic benefits of teak farms

1. Providing technical assistances for farmers to improve knowledge and understanding of proper silviculture practices.
2. Developing micro-credit institution to improve farmers' access to loans.
3. Improving market information at village level and developing business collaboration between teak growers and teak wood industries.
4. Simplifying government regulations on timber transport to reduce transaction costs on marketing.

Conclusions

Teak farms have a good potential for growth and provide employment to rural areas, but we need to address some challenges currently faced by farmers (teak growers) and improve the economic benefits of teak farm business to their households.

**Thank you
for your attention**

Photo Gallery of the Workshop



Lighting the lamp by Dr. Markku Kanninen, University of Helsinki, Director, Viikki Tropical Resources Institute, Finland/ CIFOR, Indonesia



Welcome address by Dr. N.P. Kurian, Executive Vice President, KSCSTE



Presidential address by Shri. M. P. Vincent, MLA



Objectives of the training programme by Dr. K. Jayaraman, TEAKNET Coordinator



Message from FAO by Dr. Appanah



Felicitations by Shri. P.V. Pathrose



Vote of thanks by Dr. K.V. Sankaran, Director, KFRI



View of technical Session



View of technical session



Cultural programme



Field trip: In front of the Teak Museum, Nilambur



Field trip: Government timber depot, Aruvacode, Nilambur



Dr. Mohan Kumar making the presentation



Dr. Juha Lappi making the presentation



Dr. Sudheendrakumar making the presentation



Group discussion



Training programme participants

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TEAKNET/ Kerala Forest Research Institute (KFRI)

TEAKNET established in 1995 is an international network of institutions and individuals interested in teak. The Secretariat of TEAKNET was transferred to KFRI in 2008 and started functioning with the support of FAO of Regional Office for Asia-Pacific, Bangkok. The relocated TEAKNET is committed to enhance the capacity of international stakeholders particularly teak growers, forest resource managers, processors, traders, researchers and policy makers in responding effectively to the changing social, economic and environmental needs.

The Kerala Forest Research Institute (KFRI) is one of the six institutions under the Kerala State Council for Science, Technology and Environment (KSCSTE) of the Government of Kerala, established in 1975. By conducting time-bound multidisciplinary applied research in thrust areas of tropical forestry, KFRI has created a niche among the leading forest research organizations in the tropics. KFRI has a sub-centre at Nilambur and a Field Station at Veluppadam. At Nilambur, there is a Teak Museum, the only one of its kind, devoted to a single tree species in the world; it is open to public, researchers, forest officials and others interested in teak.

Food and Agriculture Organization (FAO) of the United Nations

While FAO is a global organization, it has over the years, evinced particular interest in the Asia-Pacific region as nearly two-thirds of the world's farmers reside in this region. Along with the expansion of membership, the range of FAO activities in Asia-Pacific has also widened. The regional office assists Asia-Pacific countries with policy advice and technical expertise in agriculture, economic and social development, fishery, forestry and sustainable development to make the region food-secure for present and future generations.

Kerala State Council for Science, Technology and Environment (KSCSTE)

The Kerala State Council for Science, Technology and Environment was constituted in November 2002 as an autonomous body to encourage and promote Science and Technology related activities in the Kerala State by restructuring the erstwhile State Committee for Science, Technology and Environment (STEC) established in 1972 in concurrence with the Science Policy of Government of India. The apex body of KSCSTE is the State Council with Chief Minister of Kerala as the President. The chief executive officer of the Council is Executive Vice President (EVP).

Published by:

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KFRI CD No. 13

Typeset: KFRI

Cover Page Layout: Ebenezer Printers, Thrissur 680 012, India

