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Final report

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2 Executive summary

Smallholder teak forms a significant component of the landscape in Luang Prabang province in the northern uplands of Lao PDR. Teak is not native to this region of Laos, however has been grown in planted woodlots for more than 50 years, with some individual trees located near villages along the Mekong estimated to be several hundred years old. Consequently, there is a long history of teak growing in this region, and teak has strong economic, environmental and social importance to the peoples of this region. There is an estimated total estate of over 20,000 ha of teak planted in Luang Prabang province, with a large proportion of this owned by smallholder farmers in woodlots ranging in size from a few trees, up to around 5 ha. However, most holdings are less than 1.0 ha in size. As part of this project, permanent inventory plots were established within smallholder teak woodlots, and results indicate that these woodlots are very highly stocked, with 90% of the stands measured having stocking rates exceeding the current recommended establishment rate of 1100 trees per hectare, with stocking levels averaging between 1600 and 1700 stems per hectare across the three age classes investigated. These stocking rates are much higher than typically recommended for the production of high value timber species such as teak, and are likely to be impacting adversely on the growth and value of these woodlots. Teak woodlots represent an investment strategy for the smallholder farmer, forming a green bank from which they are able to make withdrawals through the sale of individual trees as required. Unfortunately, the absence of appropriate scientific data and extension activities this has resulted in a common misconception that all trees have value, and so highly stocked stands are regarded as being more valuable than comparable stands with a lower stocking. This has led to the current practice of using high initial stocking rates (i.e. historically 2 x 2 m and more recently 3 x 3 m initial spacing), the absence of non-commercial thinning and the common practice of thinning from above (i.e. removing the largest, highest value trees from the stand).

This project aimed to provide data that could be used in the formulation of recommendations and extension material to assist smallholder to adopt better management practices to improve the value of their teak agroforestry systems. This was a four year research project, with a one year extension that commenced in July 2008 and ended in May 2013 with on-going research activities under FST/2012/041 that commenced in August 2013. The four main research objectives were to: develop improved silvicultural systems for teak; develop improved management systems involving teak and non-timber forest products (NTFPs); develop capacity to generate and deploy improved teak germplasm; and, define economically profitable agroforestry systems involving teak and NTFPs. As implemented, this project involved the following research activities: establishment of Nelder wheels to evaluate impacts of initial spacing on teak growth and form; establishment of permanent inventory plots within smallholder woodlots as paired plots, with one plot at each site randomly selected for thinning; establishment of teak-based agroforestry trials involving a range of companion crops; selection and propagation of elite teak clones initially with cuttings and subsequently using grafting; and socio-economic research across five diverse villages to better understand the drivers of teak planting and management activities by smallholder farmers.

The research enabled the development of various teak growth models, including: predictive tree volume equations; a model to predict the mean diameter of teak stands based on measurements of age, mean stand height and stocking; and a series of site index models for young teak plantations in the Luang Prabang region of northern Laos. Two different site index models have been developed using a base age of 15 years: site index curves using the mean height of teak stands for site indices from 11 to 19; and site index curves using the predominant height of teak stands for site indices from 15 to 23.

The Nelder wheel research found that initial spacing had significant impacts on the growth and development of teak. Initial stockings around 600 trees per hectare appeared to maximise the growth potential of individual trees in the first Nelder wheel planted in 2008, and evaluated through five growing seasons to 2013. This data has supported the recommendation that smallholders use lower initial stocking rates of 600 to a maximum of 800 trees per hectare. Adoption of lower stocking rates are expected to largely eliminate the production of low value, small dimension logs in future teak woodlots.

The thinning trials demonstrated relatively small differences in the total productivity of thinned compared to unthinned plots, across all age classes. That is, the total volume of wood produced (measured as m^3 per hectare per year) was relatively unchanged by thinning in the three growing seasons following application of thinning treatments in 2009 and 2010. Superficially, it would therefore appear that there is little value in thinning these stands. However, it must be realised that the volume increment in the thinned stands is now being accrued on fewer, larger diameter trees of higher value. Therefore, thinned stands will be incrementing in value more quickly than unthinned stands. Further, when girth increments were investigated across tree size and age classes, the trials demonstrated a good response to thinning (i.e. improved girth increments) across all tree size classes in stands that were less than 10 years of age at the time of thinning, but in older stands (10-16 year old when thinned) the response was poor, and only the largest trees in these stands exhibiting reasonable (i.e. over 1 cm/year) girth increments. This indicates that teak trees, once suppressed, are either unable to respond to thinning, or will only respond very slowly to the additional space provided by thinning. Results of the thinning trials led to the following recommendations:

i) Stands aged up to 8-10 years of age, should be non-commercially thinned to a residual stocking of around 600 stems per hectare by removing small and poorly formed trees, and this thinning scheduled as early as 5-6 years after planting.
ii) Research is required to identify alternative markets for small dimension logs to encourage thinning of heavily stocked woodlots that are more than 10 years of age, as farmers are reluctant to remove these trees without an economic return on their labour and investment. Nevertheless, delaying silvicultural thinning of older stands, in the hope of a future market for small dimension logs may be detrimental, as the subdominant and suppressed trees that should be removed by thinning are growing very slowly in these woodlots.
iii) The current practice of thinning teak woodlots from ‘above’ should be strongly discouraged through the development of appropriate extension material. Removing the largest and highest value trees, adversely impacts on the long-term growth potential and value of the woodlot, as the trees removed by thinning from above are the fastest growing in the stand, while the retained trees have limited capacity to respond to the additional space provided by thinning.

Agroforestry systems involving widely spaced teak, arranged as single or paired rows aligned along the contour, demonstrated considerable promise for increasing smallholder incomes and providing an annual source of household income from the companion crops for at least four years after planting teak. These systems were able to establish viable, rapidly growing teak woodlots, and provide an ongoing source of household income to the farmers; particularly those systems that involved growing of perennial companion crops such as banana or NTFPs. Nevertheless, further research is required to develop systems that may be implemented profitably by smallholders in Luang Prabang. Improved returns on labour will be critical in the adoption of these systems, through development of methods to reduce the labour inputs and produce higher value crops.

Propagation of selected teak trees using cuttings, obtained from branches collected directly from mature trees in established woodlots, proved very difficult and success rates were low. Many thousands of cuttings were set, but only a very small number of rooted cuttings were obtained. Consequently, propagation efforts changed to the use of grafting, following a highly successful trial by NAFReC staff. A total of 100 superior trees have now been selected and successfully grafted. These grafted trees were established in a clonal seed orchard and a clone bank at Houay Khot during the 2013 wet season, and a few trees of each clone were retained in pots for the production of shoots for further vegetative propagation research. Preliminary work on the propagation of teak using tissue culture has commenced at the Agriculture Research Center at Naphok (located near Vientiane), and work has commenced on the development of tissue culture facilities for teak in Luang Prabang.

The socio-economic research reviewed the underlying incentives for the expansion of teak woodlots and examined the livelihood activities of both teak and non-teak producers. This involved village discussions, household surveys and household case studies in five villages selected to represent villages in Luang Prabang. Households in the case study villages had diverse livelihoods, hence the ability to integrate teak into the farming system varied between villages and between households within villages. Teak planting has been more extensive among households with a longer history of settlement, where the household head was older and better educated, where household members had off-farm sources of income and where the household had access to paddy land and so was more likely to be self-sufficient in rice. For these households, teak planting represents a land-use option that requires less labour input and, if managed effectively, can substantially improve household income. Indeed, it has already done so for the early adopters surveyed. While these households have more diversified livelihoods and were relatively better off compared to other members of the community, the majority of households included in the survey remain smallholder farming households with low returns to land and labour, and low incomes.

For households that depend on shifting cultivation for their livelihoods, incorporating teak systems into their livelihoods remains challenging. Several agroforestry systems have evolved that present opportunities for income generation in the early years of establishment. However, these systems require additional labour and are less likely to be adopted by households with non-farm employment or other productive agricultural activities (e.g. paddy rice and vegetable gardens). The research reveals that the establishment and improvement of teak woodlots and agroforestry systems, like other technical interventions aimed at providing a ‘pathway out of poverty’, need to be seen in the context of the wider processes of agrarian change and differentiation, to appreciate the resultant impacts on livelihood trajectories. As such, extension materials on stocking, spacing and management need to capture the diversity of household situations and be targeted accordingly.

3 Background

Smallholder teak (*Tectona grandis*) plantations have become increasingly prominent in the landscape of Luang Prabang Province, Lao PDR. While the global market for teak-wood is attractive, smallholder investment in establishment of teak woodlots has been driven by a range of factors, including changes to land legislation, land-use planning, taxation incentives, and government and non-government programs and promotions. The establishment of teak woodlots provides a labour-saving land use for households, potentially freeing-up household resources for other farm and non-farm activities. However, the degree to which households can participate in the teak industry varies within and between villages. As such, both smallholders and urban-based landowners are now involved in small-scale teak woodlots in Luang Prabang province, either by planting land they previously used for swidden agriculture or by acquiring existing teak stands.

Individual trees are typically harvested from around 12-15 years after planting, to supplement household incomes, often to meet a specific need (e.g. medical or educational expenses). However when switching from annual crops to longer term crops such as teak, farmers must be able to ensure that they have other sources of income to sustain their household while they wait for the teak trees to reach a commercial size. This is particularly an issue for poorer households with limited land available to produce annual crops for income or subsistence, and for those household which aren’t able to source income from off-farm activities. Consequently, many farmers may not be able to take advantage of the long-term benefits of teak planting because they require an annual return from their land to maintain their household livelihood. Further, in some areas, the inappropriate conversion of farming land to monoculture teak may be leading to forced sales of land in times of financial difficulty.

Teak plantations in Luang Prabang have been typically planted at relatively high plant densities (> 1600 stems per hectare), although currently initial spacing of 3 x 3m (i.e. an initial stocking of approximately 1100 sph) is recommended. Due to the resulting dense canopy of teak, woodlots grown at these stockings will usually suppress most understory vegetation, increasing the risk of soil erosion and preventing the cultivation of companion crops with the teak. These woodlots have been established for the production of teak logs, primarily using an agroforestry system commonly referred to as Taungya (Evans and Turnbull 2004) where the teak is interplanted into annual crops such as upland rice, maize or Job’s Tears (*Coix lacryma-jobi*), or with perennial crops such as pineapple, banana, paper mulberry (*Broussonetia papyrifera*) and/or broom (tiger) grass (*Thysanchaena maxima*). Companion crops are commonly grown with teak for the first two years, but can in some cases for three to four years after the teak is planted. The combination of crops and trees on the same land adds other dimensions to the silvicultural management of the teak plantings (Cameron *et al.*1989).

Optimising economic returns from teak woodlots requires an intimate knowledge of its growth habits and an understanding of the effects of competition for light and space (including any inter-row crop species). Intense competition between trees, and other vegetation, often leads to poor tree growth, disease and death. One of the main causes of reduced tree vigour in plantations is inter-tree competition between crowns for both space and light. The suppression of crown expansion in most tree species leads to a rapid decline in girth increments, and hence the production of timber from suppressed trees. This phenomenon has led forest managers to realise that for many tree species there is a strong connection between canopy extension and girth of a tree’s trunk (e.g. Jacobs 1955, Suri 1975 and Hemery *et al.* 2005). It has also been recognised that the restriction of crown expansion, does not initially translate to a reduction in the growth in tree height but may assist in reducing the size and quantity of side branches. This has led to the understanding that the stocking of tree plantations can be manipulated in order to optimise both tree growth and timber quality. The management of woodlots for timber production using tools such as early selection of superior trees, pruning and thinning, is designed to maximise growth and wood quality, and thereby providing the highest possible returns to the woodlot owner.

There is a common misconception among teak smallholders, both in northern Laos and other regions such as Indonesia (Kallio *et al.* 2012), that the planting and retention of the largest numbers of trees on their land will provide the highest financial returns, and that all trees will eventually have a commercial value (i.e. can be sold for the production of sawn timber). This leads to the adoption of high initial stocking rates, a reluctance to remove any trees until they reach sufficient size to be sold for the production of sawn timber, and the common adoption of thinning from above whereby the larger trees in the stand are removed at thinning rather than the smallest trees (i.e. thinning from below).While high stocking rates will typically maximise stand productivity per unit area (i.e. total volume per hectare), but restricts the girth increment and hence size of individual trees, and hence will not necessarily maximise the stand value in terms of either $/ha or net present value. However, for high value hardwoods such as teak where value is strongly determined by tree size and timber quality (e.g. heartwood percentage and absence of defects), stand value will normally be maximised by lower stocking rates and aggressive thinning regimes that accumulate basal area increments on retained dominant trees through the removal of suppressed and poor quality trees.

The impact of various stocking rates on tree growth has been demonstration for many tropical and temperate tree species through the establishment of Nelder wheels (Nelder 1962), for example, multiple species (Mark 1983), *Quercus mongolica* (Imada 1997) and *Eucalyptus grandis* (Congdon and Addison 2003). Nelder wheels have been used to examine the effects of light regimes on inner-row and sub-canopy crops as the trees have grown (*Eucalyptus grandis* – Cameron *et al*. (1989) and *Khaya senegalensis* – Addison (2003)). A Nelder wheel provides a continuum of tree densities (stems per hectare, sph) radiating out from the centre, from high to low density, along the spokes or rows of the wheel (Parrott *et al.* 2012). This experimental design is an excellent indicator for determining optimum initial spacing between seedlings (Mark 1983), and provides evidence of the space required to maximise and maintain tree growth.

The research framework of this project seeks to provide evidence to support improved management of teak woodlots and teak-based agroforestry system in Luang Prabang province of northern Laos, with the ultimate aim of improving livelihoods and minimising risks that interventions may adversely impact on the rural poor. The project is structured around four research objectives investigating: impacts of spacing and thinning on teak woodlots; potential of teak-based agroforestry systems; genetic improvement of teak to underpin a sustainable teak resource; and the socio-economic drivers of teak growing by smallholders.

4 Objectives

This research project focused on generating information that may be used to support improvements in the management of teak woodlots in Luang Prabang province of northern Laos, with the ultimate aim of enhancing the income of smallholder farmers living in the upland regions of northern Laos. To facilitate this, research was conducted on: a) improved silvicultural management of teak plantations to increase the size and/or quality of the timber produced leading to higher economic returns, b) development of agroforestry systems involving teak, to allow farmers to maintain annual incomes from land planted with teak for the first 6-8 years after planting teak, and c) implementation genetic improvement of teak, allowing lower initial stocking rates and improved productivity. The overarching objective was to better understand the socio-economic drivers of current management practices and any impediments to the adoption of improved management practices. The project focused on the Luang Prabang province of northern Lao PDR.

Underpinning objectives and activities as stated in the project proposal are listed below.

Objective 1. Develop improved silvicultural systems for teak, leading to productivity increases through improved growth and form.

Activities:

- Evaluate spacing-growth-form relationships in existing teak plantings (established by NAFRI, farmers and other participants).
- Establish and evaluate thinning trials in some of these existing plantings.
- Establish a network of demonstration plantings utilising a Nelder Wheel design to provide clear visual demonstration of effects of competition on growth and form in pure teak and teak/paper mulberry plantings.
- Determine relationships between spacing and tree growth to develop recommendations to optimise returns from existing and future plantations of teak.

Objective 2. Develop improved management systems for mixed species plantations involving teak and commercial non-timber forest products.

Activities:

- Evaluate the effects of interplanted non-timber forest products (NTFPs) on the growth and form (i.e. branching, bole length, stem straightness and crown defects) of teak, with an initial focus on teak + paper mulberry.
- Establishment of a network of demonstration trials. These trials will use a Nelder Wheel design to provide clear visual demonstration of the effects of spacing and competition tree size and form.
- Investigate impacts of spacing and competition on growth and form of teak and paper mulberry. This will utilise data from the Nelder Wheel plantings, as well as trials established on-farm.
- Collate information on other NTFPs that might be used in mixed plantings with teak. This will mostly involve collaboration with other agencies working in Laos (e.g. SIDA, SNV, and CIAT), and aims to identify a short list of the most promising species.

Objective 3. Develop capacity to generate and deploy improved teak germplasm at the village level.

Activities:

- Identify superior teak trees within plantations and vegetatively propagated by cuttings.
- Selected trees will be established in hedges and multiplied by cuttings, with trials established on-farm using small disconnected incomplete blocks.
- Elite clones will be selected and distributed to all participating villages.
- Village-based nurseries will be established, and training provided to allow multiplication and propagation of elite clones at the village level.

Objective 4. Define economically profitable agroforestry systems involving teak and NTFPs.

Activities:

- Conduct economic analyses of alternative teak-NTFP agroforestry systems that are suggested by the outputs of Objectives 1 and 2.

Teak and teak + NTFP systems will be evaluated in relation to alternative land uses, and consider social, economic and environmental impacts of changing land management practices.

5 Methodology

5.1 Teak Silviculture Research (Objective 1)

The teak silviculture research focused on impacts stocking rates on the growth of teak, and involved two components:

1. Establishment of Nelder wheels on three sites to investigate impacts of initial stocking (100-2500 sph) on the growth and form of teak, and evaluate potential for significantly reduced initial stocking rates; and,
2. Establishment of thinning trials within smallholder woodlots, distributed throughout the target region to investigate impacts on thinning (non-commercial) of highly-stocked stands up to 16 years of age, on subsequent growth rates.

5.1.1 Nelder Wheels

Northern Agriculture and Forestry College

Site Characteristics

History – Originally a tropical rain forest on the banks of the Mekong River, slashed and burnt, then periodically cropped over a number of years. Crops have included maize, bananas, and cassava.

Pre-plant site preparation has included brushing of numerous soft broadleaf weeds, bananas, vines and grasses. Small saplings were also fell and remove along with most cut vegetation. Ploughing with a wheel tractor and 7 disc plough then followed.

Unfortunately the block of land allocated, for this experiment, was 10 metres short in the E –W direction, but further clearing over a fence enabled the full 50m spokes to be established in that direction. This extension was not ploughed. (See layout diagram, Figure 5.1)

Site Planted: 29th July 2008

Aspect: near level

Slopes: spokes range from 0º to 1º, generally 0.5º.

Soil: Black clay loam, probably alluvial.

Altitude: approx. 290m asl.

GPS coordinates of Nelder Wheel pivot: N 19° 59.3’, E102° 14.6’

Design and Layout

The experiment comprises two components:

- a Nelder Wheel planted with teak of two provenance origins, and;
- unreplicated blocks of teak established in the unutilised land around the central Nelder Wheel.

Nelder Wheel:

Number of spokes per quadrant: 6 (3 Myanmar teak + 3 Luang Prabang (LP) teak)

Total number of spokes: 24 (12 Myanmar teak + 12 LP teak in alternate spokes).

Angle between spokes: 15º

Total number plants: 240 (120 for each teak provenance)

Gross area of wheel: 0.7854 ha

Initial Spacing: 8 (refer Table 5.1)

Isolation: Trees 1 and 10 (refer Table 5.1)

Table 5.1: Design parameters of the Nelder wheel.

Tree	Radius (m)	Interval Spacing (m)	Cross Spacing (m)	Av. Spacing (m)	Area/tree (m²)	Stocking (sph)
10	50		13.1	Isolation		
9	40	10	10.4	9.7	94.5	105.8
8	32	8	8.4	7.9	62.8	159.1
7	25	7	6.5	6.3	39.2	254.9
6	20	5	5.2	4.9	23.6	423.3
5	16	4	4.2	4.0	15.7	636.6
4	12.5	3.5	3.3	3.1	9.8	1019.7
3	10	2.5	2.6	2.5	6.0	1658.8
2	7.9	2.1	2.1	2.0	4.1	2423.9
1	6	1.9	1.6	Isolation		

Unreplicated Block Plantings:

4 spacings: - 2m x 2m = 2500 sph

3.3m x 2m = 1500 sph

5m x 2m = 1000 sph

5m x 4m = 500 sph

1 replication of each spacing

1 teak provenance (Myanmar)

Isolation: 1 row/tree (refer layout diagram – Figures 5.1)

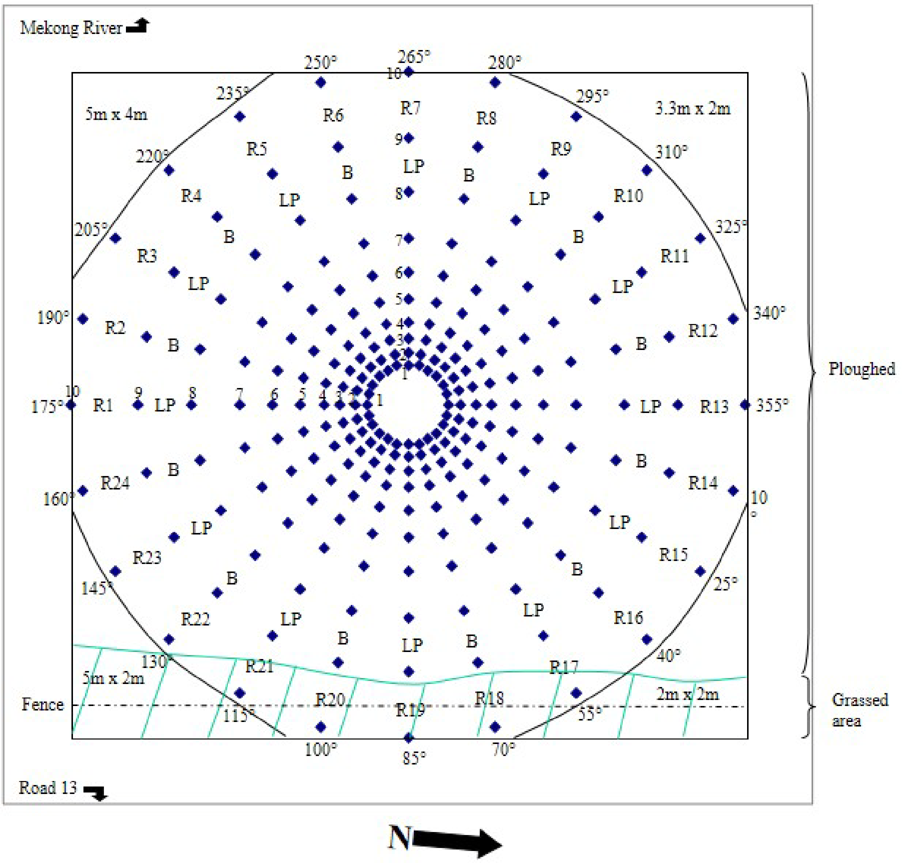

Figure 5.1: Layout of the Nelder wheel and unreplicated teak planted at the Northern Agriculture and Forestry College in 2008.

Nursery history

The teak seedlings were raised at the old Teak Research Station at Kien Ben, on the Nam Xeuang. The seed was broadcast sown in April 2007 into a cultivated bed. When seedlings were approximately 15 months old, they were lifted and stumps prepared for planting on 29/07/2008.

Seedlings used are of two different provenance origin. Myanmar (or Burma or 'Golden' teak) using seed collected from blocks planted near entrance of the old Teak Research Station (now police training centre). The other source is from seed collected in villages plantings along the Nam Xeuang, and is considered as local, Luang Prabang, provenance.

Souphanouvong University

Site Characteristics

History – Originally a tropical rain forest on the banks of the Mekong River (Nam Khong), which had been cleared for agriculture many years earlier, abandoned and secondary forest partially re-established on the site. Regrowth was slashed and burnt during March and April 2009. Clearing was rather late in the dry season due to shortage of labour. Consequently, burning was not hot enough to kill stumps of cleared vegetation, and a significant amount of debris remained on the site. This required re-clearing. A small part of the Nelder Wheel site was an existing teak plantation (approx. 15 years old), that was felled and cleared in May 2009.

Pre-plant site preparation included brushing of numerous soft broadleaf weeds, stump coppice, vines and grasses. Small saplings were also felled and burnt (or removed) along with most the other cut vegetation.

The site nominated, and amount of land cleared, was too narrow to establish a complete Nelder wheel (i.e. the site was less than 100m wide), therefore establishment of the two planned Nelder wheels was impossible on the land available. To secure adequate land to establish a ½ Nelder wheel it was necessary to clear part of an adjoining young teak plantation as well as incorporate part of an old access road within the Nelder wheel. The teak plantation was cleared back as far as possible from the edge of the Nelder to minimise shading on the eastern side of the wheel. In total it was only possible to establish 14 spokes of a Nelder wheel.

Site Planted: 2nd June 2009

Aspects: north and south

Slopes: spokes range from –1º to +5.5º, generally 3º.

Soil: alluvial brown sandy clay loam.

Altitude: approx. 290m asl.

GPS coordinates of Nelder Wheel pivot: N 19º 55.7', E102º 11.5'.

Design and Layout

The experiment comprises three components:

1. A partial Nelder Wheel (14 spokes) planted with a single provenance (Luang Prabang) of teak, and
2. Unreplicated blocks of teak established around the central Nelder Wheel, and
3. Two replications of four spacings as block plantings, west of the Nelder Wheel.

Nelder Wheel:

Total number of spokes:	14
Angle between spokes:	15º
Total number plants:	140 (10 per spoke)
Gross area of wheel:	0.2672ha
Number of initial stockings:	8 (same as College Nelder, above)

Isolation: Trees 1 and 10 (refer Table 5.1, above), and outside two spokes 1 and 14.

Unreplicated Block Plantings: (around Nelder Wheel)

4 spacings:-	2m x 2m	= 2500 sph
	3.3m x 2m	= 1500 sph
	5m x 2m	= 1000 sph
	5m x 4m	= 500 sph

1 block of each spacing

1 teak provenance (Luang Prabang)

Replicated Block Planting: (west of Nelder Wheel, Figure 5.2)

4 spacings:-	2m x 2m	= 2500 sph
	3.3m x 2m	= 1500 sph
	5m x 2m	= 1000 sph
	5m x 4m	= 500 sph

2 replications of each spacing, treatments (spacings) randomised.

1 teak provenance (Luang Prabang)

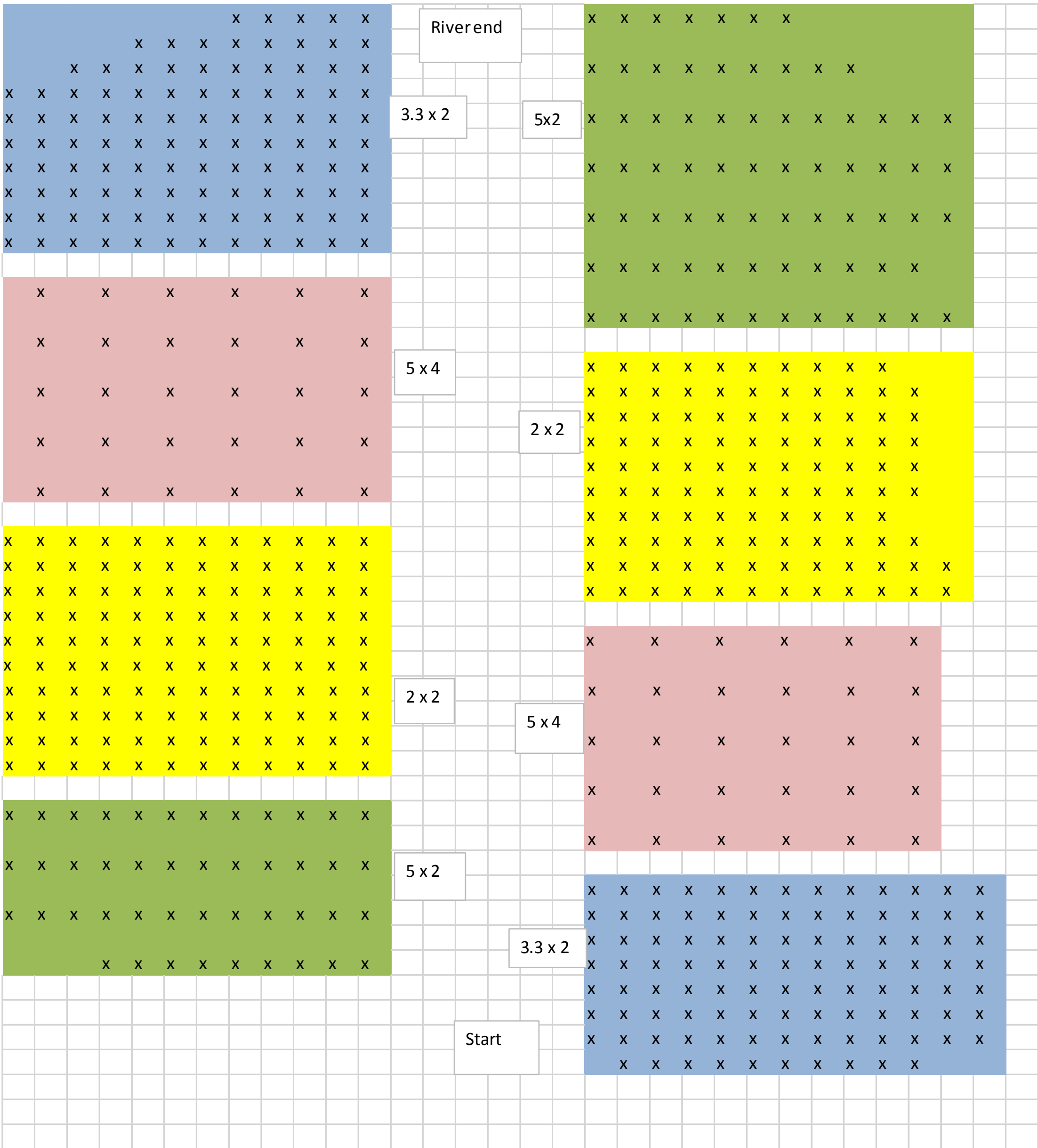

Figure 5.2: Replicated teak blocks planted at Souphanouvong University in 2009.

Nursery history

Teak raised at the NAFReC (Houay Khot) nursery, as seedlings that were broadcast sown in a cultivated nursery bed in May 2007. Stumps were lifted and prepared in the week of 25/05/2009. At planting the teak stumps were approximately 24 months. Seed was collected in January 2006 from village plantings along the Nam Khan, and so considered to be local, Luang Prabang, provenance.

Thong Khang

Thong Khang village region is within the Nam District and is the home of the Laolum, Aion and Kamon ethnic people. The research site is 65km south of Luang Prabang in the Luang Prabang province of Lao PDR. The site came under the control of the National Agriculture and Forestry Research Centre (NAFReC) in 2005.

Site Characteristics

History – Originally a tropical rainforest, slashed and during 1971/72, then periodically cropped over a number of years. Crops have included maize, Job's tears and upland rice.

Site preparation included brushing of soft broadleaf weeds, vines and Imperata grass. An experimental maize crop (to 30cms in height), intruded into the Nelder Wheel area (Figure 5.3).

Site Planted: 30th July 2008

Aspect: North Easterly

Slopes: spokes range from -7º to +5º .

Soil: Red brown clay loam

Altitude: approx. 680m asl

GPS coordinates of Nelder Wheel pivot: N 19º 35', E101º 59'

Design and Treatments

The experiment comprise of two components:

i) Nelder Wheel planted with teak and paper mulberry, and

ii) Small unreplicated blocks of teak established around the central Nelder wheel.

Nelder Wheel:

Number of spokes per quadrant:	6 (3 teak + 3 paper mulberry)
Total number of spokes:	24 (12 teak +12 paper mulberry in alternate spokes).
Angle between spokes:	15º
Total number plants:	240 (120 teak + 120 paper mulberry)
Gross area of wheel:	0.7854 ha
Initial spacings:	8 (refer to Table 1)
Isolation:	Trees 1 and 10 in each spoke (refer to Table 1)

Note: spokes 11, 12, 13, 14, 15 and 16 were shorter than required by design due to irregular shape of the block (See Figure 5.3).

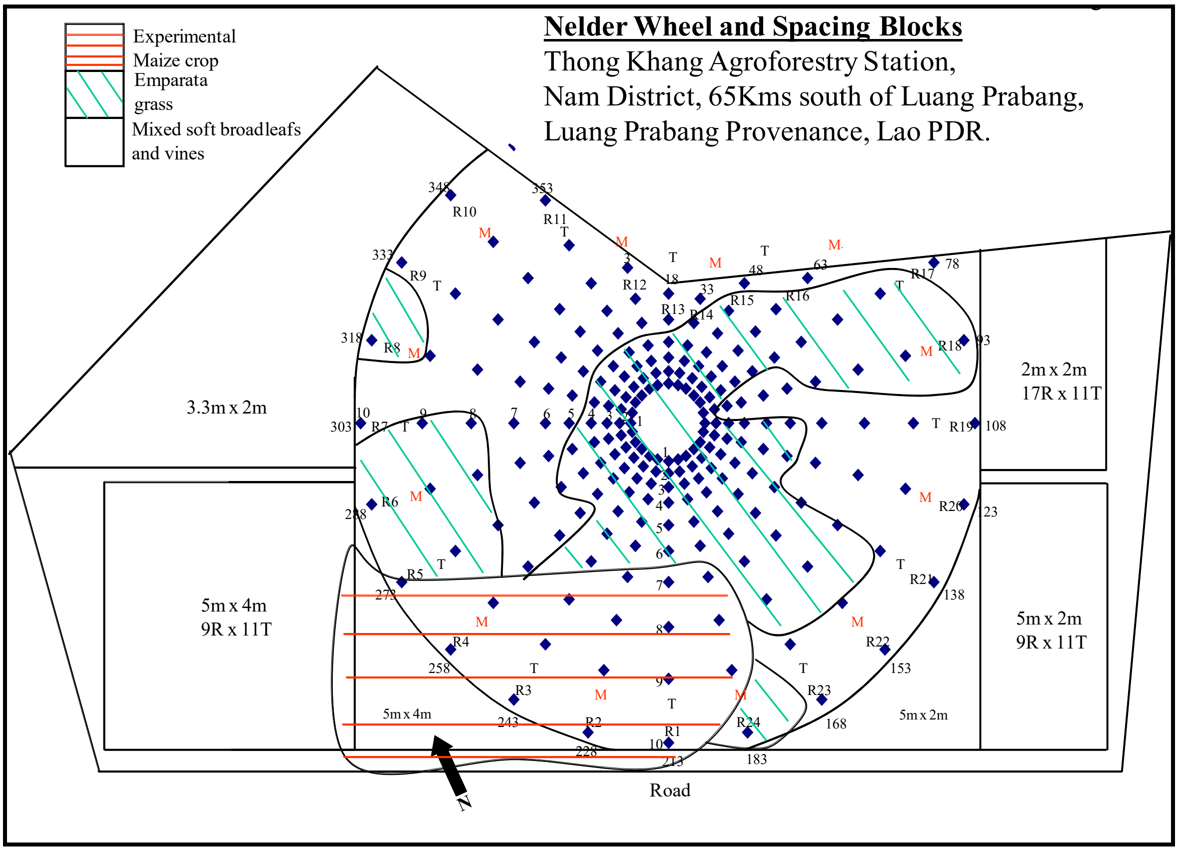

Figure 5.3: Nelder wheel and variously spaced teak blocks planted at Thong Khan in 2009.

The survival of paper mulberry at this site was extremely poor. Almost all paper mulberry were replanted at the start of the 2009 wet season (June). However, a year later (May 2010) its survival was again very poor. The main factors contributing to this situation were identified as severe water stress during the dry season and termites (paper mulberry appears to be very susceptible when young). All paper mulberry spokes were replaced with teak in May 2010.

Overall the growth of teak at this site was also poor, although its survival was generally good. The growth of teak remained poor at this site, despite the addition of fertilizer (superphosphate 50g/tree, and powdered sulphur 5g/tree), which was applied in two slits either side of each teak tree on 4 August 2010. The poor growth of teak on this site is presumed to be a result of the previous cropping of this site that depleted available nutrients. This experiment has now been abandoned, and a new experimental site has been selected.

5.1.2 On-Farm Thinning Trials

In 2009 and 2010 a series of thinned/unthinned plots in smallholder teak woodlots were established across villages in four districts of Luang Prabang province (Table 5.2). These were predominantly established as sets of paired plots – one control plot (i.e. unthinned) and the other treated (i.e. thinned). However, in some cases it was not possible to include an adequate control plot, or three plots were established on a site (i.e. two treatment plots and one control plot). The primary intention of these paired-plots was to quantify the potential benefits that may accrue to local farmers from thinning teak woodlots at various ages and initial stocking levels. Establishment of plots followed extensive periods of consultation and negotiation with communities and individual farmers. Farmers with suitable woodlots who were interested in participating in the project were selected, plots established in representative areas of the woodlot that had reasonably uniform stocking.

Table 5.2. Summary of plots established by village and district.

Village	District	Number of Teak Farmers	Number of Plots
Ban Kok Gniew	Luang Prabang	6	15
Ban Lak Sip	Luang Prabang	8	15
Ban Xienglom	Luang Prabang	6	18
Ban Ean	Xieng Nguen	3	6
Ban Nasao	Luang Prabang	1	2
Ban Pik Noi	Luang Prabang	1	1
Ban Pik Ngai	Luang Prabang	1	2
Ban Densavanh	Luang Prabang	2	4
Ban Sanok	Chomphet	2	4
Ban Dane	Nan	2	5
Ban Thong Khang	Nan	1	2
Ban PhaTongLom	Nan	1	3
Totals		34	78

Installation of permanent plots

In the original project documentation, it was proposed to establish circular plots. However, due to the irregular shape of the woodlots it proved too difficult to establish circular plots. Whereas, small square plots could often be arranged side-by-side within relatively small teak blocks. Therefore, after discussions with the Lao partners, it was decided to change to a primary measure plot (i.e. the net plot) size of 18 x 18 metres, with a gross (isolation) plot size of 22 metres by 22 metres (horizontal distances); see Figure 5.4. Plots were aligned so that the side at the top of the slope was oriented as close to the contour as possible (always less than 5 degrees), with sides running between planting rows (if obvious). However, as the sides of each plot were established at a strict 90 degrees from the base line, and planting lines were not often arranged in straight lines, the sloping sides of the plot sometimes did not pass down the centre of two planting lines. The length of each side was adjusted for slope as required. Plots were established primarily in pairs for research and demonstration purposes and were adjacent to each other if possible (~50% of plots) to minimise any site differences within each pair of plots.

While most of the were established in 2009 had the exact dimensions described above, plots established in the second year (2010) were arranged to ensure plot edges ran through the centre of planting lines (where obvious), and plots were made smaller when a plantation was smaller than necessary for the two 22m plots. The 'top line' was established the same as the 2009 plots, with the end points placed to be between two planting rows (where present). The side rows then ran down the planted lines for 22 metres (shorter if required to avoid the edge of the woodlot). The final line was then established between planting rows to form the complete gross plot. The net plot was then established one line in from the net plot so there was one full line of trees in the ‘isolation area’. As planting lines were often not established in straight lines or at right angles, the resulting plot was often not exactly square or rectangular in shape. The gross and net plot areas were calculated by taking all the side lengths of both the gross and net plots, plus diagonals, plus the corresponding slope of each side and the diagonal. The plot size was then calculated using trigonometry. The plot sizes established in 2010 are then varied, and these are recorded in the basic metadata spreadsheet.

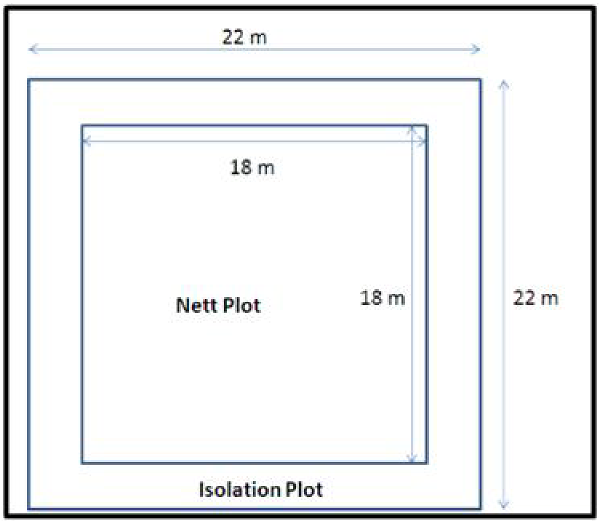

Figure 5.4: Basic plot dimensions (in the horizontal plane). Plot boundary lengths were adjusted for slope when slope exceeded 5 degrees (Note: plots established in 2010 did not follow these exact dimensions as explained in text).

All trees were numbered (Figure 5.5). Trees were initially numbered using spray paint and then subsequently marked using aluminium tags fixed to the base of every tree with a wire loop or affixed with a small nail (below 10cm above ground). Plots were marked with either large wooden posts or smaller pegs depending on the distance from road access. These corner posts / pegs were placed at the corner of each measure plot and were painted white. The location of each plot was recorded using a handheld GPS.

Figure 5.5: Thinned plot at Ban Phatonglom (Photograph by Sean McNamara, June 2009).

Thinning treatments

One plot in each pair at each site was randomly selected for treatment. The target residual stocking was 800 sph; however, stocking was generally not reduced by more than one third. Farmers were reluctant to agree to the removal of sufficient trees to reduce highly stocked stands to the target residual stocking. Further, we were concerned that heavy thinning might result in wind-damage (top breakage, leaning stems and wind-throw) to the retained stems. Therefore, where the initial stocking was over 1200 sph, the residual stocking rates were sometimes much higher than the target of 800 sph, as usually no more than one third of the standing trees were removed by thinning. Treatment plots were randomly allocated within woodlots, and stocking was reduced in the treated plots by removing small, malformed, leaning and multiple stems. On three sites, it was possible to establish three plots, and in these cases two plots were thinned, and a lower residual stocking (600 sph) was adopted for the second treatment plot.

When marking the plots for thinning, the net and gross plot areas were treated separately and the number of trees required to be removed from each determined separately. Trees to be thinned were selected and marked by project staff and the plantation owner. Under performing trees and trees with bad form were selected first, and then trees were selected for thinning to provide space for the retained trees.

Prior to thinning any trees, written agreements were made between the farmers and NAFReC detailing the number of trees to be removed, and amount of compensation[1] that would be paid to the owner for the trees to be removed. The agreement also included a small payment for participation in the project and a payment to be made at the conclusion of the experiment if the farmer is still participating (i.e. still owns the land and had not cleared the trees by the end of the trial period). Once these agreements were signed and payments to farmers made, the nominated trees were thinned during June 2009 or May 2010. The farmers retained ownership of the thinned stems and were encouraged to place stems and sticks that were not to be removed from the site across the slope as an erosion control measure. In some cases, the farmer did not agree to proceed with the thinning, this resulted in only one set of data for the site.

Metadata and plot data

For each woodlot metadata including age, location (latitude and longitude), elevation, and aspect were recorded (Table 5.3). At plot establishment, each tree was numbered and permanently marked. The measured plot area (horizontal projection) and number of stems per plot were used to estimate stocking (stems per hectare, sph). Measurements recorded at plot establishment included plot area, age and stocking, along with individual tree measurements of total height (to nearest 0.1m using a Vertex Forester[2]), and diameter over bark (DBH; at 1.3m) over bark (to nearest 0.1cm using a calibrated DBH tape). Except for the initial measurements in 2009, when plots were measured at the start of the wet season (May 2009), all measures were conducted in the December/January period

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[1] Compensation based on girth at breast height of trees removed: less than 20 cm = $0; 20-30 cm = $1, 30-40 cm = $3, over 40 cm $5. These were not payments for the trees, as the farmers retained all timber removed by thinning.

[2] Due to malfunction in the Vertex, two plots were not measured for height when plots were first established in 2009.

during the dry (non-growing) season. In this way the differences between successive measures represent the annual increment in a single growing season.

Plots were revisited regularly to check that tags had not been removed and that trees and plots could be easily identified. Each tree was re-numbered with spray paint, and the DBH measure point remarked. The condition of corner posts was also checked at this time.

Measurement data were used to calculate a variety of derived parameters at both the individual tree and plot levels. These parameters were:

- Tree volume, using derived individual tree volume equations (m^3);
- Diameter, height, basal area (i.e. cross-sectional area) and volume increments (cm yr^{-1}, m yr^{-1}, m^2 yr^{-1} and m^3 yr^{-1});
- Count of the number of trees by diameter class[3], pre- and post-thinning;
- Stocking, pre- and post-treatment (stems ha^{-1});
- Standing basal area calculated as the sum of the cross-sectional areas divided by plot area (m^2 ha^{-1});
- Standing volume calculated as sum of tree volumes divided by the plot area (m^3 ha^{-1}); and,
- Predominant height of each plot calculated as the mean of the 2-3 tallest trees per plot (approximately, mean of the tallest 50 trees per hectare).

Table 5.3: Landowner and site details.

Site	Village	Owner	Latitude	Longitude	Year Planted
1	Ban Kok Gniew	Mr Khao	N 19 51.394	E 102 12.683	2004
2	Ban Kok Gniew	Mr Khao	N 19 51.028	E 102 12.517	1994
2	Ban Kok Gniew	Mr Khao	N 19 50.988	E 102 12.480	1994
3	Ban Kok Gniew	Mr Khampeng	N 19 51.018	E 102 11.211	2004
4	Ban Kok Gniew	Mr Somphet	N 19 51.100	E 102 13.022	2003
5	Ban Kok Gniew	Mr Thongkan	N 19 50.988	E 102 11.434	1994
6	Lak Sip	Mrs Sher	N 19 50.693	E 102 10.203	1996
7	Lak Sip	Khamam Savathoun	N 19 50.641	E 102 10.312	1999
8	Lak Sip	Keo Oudon	N 19 50.790	E 102 10.438	1997
9	Lak Sip	Sounthoug Souksavath	N 19 51.033	E 102 10.454	1996
10	Lak Sip	Mrs Khamivoung	N 19 50.955	E 102 10.383	1996
11	Lak Sip	Mr Ountha	N 19 51.230	E 102 10.347	1997

[3] *The trees in each plot were divided into 2 cm size classes determined by the measured tree size in the measurement when the plots were first establishment. The diameter class name is the mid-point of this range (i.e. 1 (0 cm to less than 2cm), 3 (2cm to less than 4cm), 5, 7, 9…).*

12	Lak Sip	Mr Ountha	N 19 51.233	E 102 10.317	2006
13	Lak Sip	Loung Bong	N 19 51.130	E 102 10.120	1998
14	Ban Ean	Mr Boundouan	N 19 49.931	E 102 12.702	mixed
15	Ban Ean	Mrs Chanxi	N 19 50.197	E 102 12.739	1997
16	Ban Ean	Mrs Chanta	N 19 50.173	E 102 12.798	1993
17	B. Xienglom	Pung noi pa	N 19 52.954	E 102 14.989	2002
18	B. Xienglom	Pung noi pa	N 19 52.791	E 102 14.691	2000
19	B. Xienglom	Pung noi pa	N 19 52.930	E 102 14.480	2005
20	B. Xienglom	Pung noi pa	N 19 52.801	E 102 14.671	2000
21	B. Xienglom	Mr Sichanh	N 19 51.880	E 102 14.180	2005
23	Ban Dane	Mr Khenj	N 19 34.196	E 101 59.579	1995
24	Ban Dane	Mr Xieng Oun	N 19 34.289	E 101 59.461	1995
25	Ban PhaTongLom	Champheng Didsaphon	N 19 35.184	E 101 57.617	1995
26	Ban XiengLom	Mr Xieng Champa	N 19 52.783	E 102 14.703	2000
27	Ban XiengLom	Mr Sing	N 19 52.835	E 102 14.746	2000
28	Ban Naxao	Mr Khamsai Soulivong	N 19 49.689	E 102 02.770	1995
29	Ban Naxao	Somphone Manesone	N 19 49.576	E 102 03.610	1996
30	Ban Sanok	Mr Bouapheng	N 19 56.602	E 102 11.948	1996
31	Ban Lak Sip	Mr Bounsamay	N 19 50.745	E 102 10.147	unknown
32	Ban Sanok	Mr Bounkong Thapon	N 19 56.316	E 102 12.336	1996
33	Ban XiengLom	Mr Houmphan	N 19 52.696	E 102 14.595	2002
34	Ban XiengLom	Mr Thid Lid	N 19 52.156	E 102 14.409	2002
35	Ban Densavanh	Mr Phandon	N 19 54.464	E 102 15.376	2001

Site	Village	Owner	Latitude	Longitude	Year Planted
36	Ban Densavanh	Mr Phandon	N 19 54.439	E 102 15.372	2001
37	Ban Pik Ngai	Mr Phoumpasert	N 19 54.484	E 102 14.253	1999
38	Ban XiengLom	Mr Chandee	N 19 53.424	E 102 15.062	1999
39	Ban Kok Gniew	Mr Thongkhoun Ngai	N 19 51.286	E 102 13.001	2005
40	Ban Kok Gniew	Mr Onse	N 19 51.387	E 102 12.481	2005
41	Ban Pik Noi	Ounkham Keomanichan			unknown
42	Ban Dane	Mrs Vi	N 19 33.884	E 102 00.221	unknown

5.1.3 Volume Equations

Growth rates can be readily measured in terms of tree diameter and height, but in order to accurately evaluate the economic value of the measured response to thinning, it is also necessary to be able to monitor changes in tree volume.

Discussions with the Laos project partners revealed that there were no appropriate tree volume equations for small, plantation grown teak trees. Similarly, there were no reliable volume equations available (from a search of the published literature) to estimate standing volumes in young teak plantations in this region.

The primary aim of this component of the project was to develop small-tree volume equations for use within the project, and volume equations that could be used as part of an inventory of smallholder teak woodlots.

Selection of Sample Trees

Sample trees were selected from teak woodlots owned by farmers participating in the ACIAR project. Younger trees (8-12 years) were chosen, so that the equations developed would be representative of the target ages for non-commercial thinning. Two sites with well-managed plantations, that had not been thinned or pruned, apparently growing normally, and which were considered to be representative of smallholder woodlots in the region, were selected for this study. The trees had been previously measured when establishing the paired-thinning plots, and sample trees were selected from across the diameter distribution in these measured plots. Determination of tree volume on standing trees requires measurement of upper-stem diameter; consequently with the relatively basic equipment available in Laos (e.g. bamboo ladder) and steep topography, due to safety considerations it was not possible to measure standing trees larger than 20 cm in diameter at 1.3m. Therefore, in order to overcome this limitation, larger (and older) trees were opportunistically included in the sample as the trees were being harvested, to expand the diameter range of the sample trees to approximately 30cm.

Volume Estimation – Sample Trees

The total volume of each sample tree was estimated using the centroid method (Wood and Wiant 1990; Wiant *et al.* 1992) which only requires one upper-stem measurement of diameter. Wiant *et al.* (1996) recommend application of the centroid method to tropical hardwood species where reliable volume equations are not available, as this method has been demonstrated to provide both precise and relatively unbiased estimates of tree volume (Wood and Wiant 1990, 1992; Wood *et al.* 1990; Wiant *et al.* 1996; Coble and Wiant 2000) in a range of tree species including hardwoods (Wiant *et al.* 2002), and can be readily applied to standing trees. A slight (negative) bias has been reported for the centroid method in some studies (e.g. Wiant *et al.* 1996); however, Leech (1996) suggests that this bias is too small to be of any practical significance. Although this bias can be eliminated by inclusion of an additional upper-stem sampling point (Williams and Wiant, 1998), this adds considerable complexity to the method, and also significantly increases the cost and time required, and so was not feasible here.

The measured characteristics required from each sample tree for the centroid method are: total tree height (Ht), diameter over bark (DBH) at both breast height (1.3m), diameter over bark at the centroid height (DCH) and bark thickness (BT) at breast height. For a full description of the calculation of both the centroid height and tree volume, see Wiant *et al*. (1992). When determining the centroid height, stump height was set at zero, and merchantable height was set to the total height of each tree, as we were interested in an estimate of the total under-bark volume of each tree.

Tree height was measured with a Vertex Forester hypsometer (average of three measurements; height of the highest green shoot) to nearest the 0.1 m, diameters were measured with a diameter tape to the nearest 0.1 cm, and bark-thickness as the average of four equidistant measures with a bark-gauge (to nearest 0.5 mm) at breast height. The centroid position was determined using a tape measure. For measurements on standing trees, a bamboo ladder was used to reach the centroid point. For the larger (felled) trees subsequently included in the sample, height, DOB and bark thickness were measured in the same way as for standing trees, but the diameter at the centroid position was measured after each tree had been felled.

Data Analysis – Tree Volume Equations

A total of 77 sample trees were measured: 41 trees from Ban Kok Gniew, 25 trees from Ban Naxao and 11 larger trees that had been felled. However, exploratory data analysis indicated that one tree from Ban Kok Gniew had an unusually small CDH, and the recorded total height for four of the eleven larger trees was apparently too small for their DBH. These trees were excluded and the remaining 72 trees (Table 5.4) were used in subsequent analyses. Regression analyses with PROC REG in the SAS statistical package (SAS Institute Inc., 1989) were used to develop equations relating DBH and/or height to tree volume. Models selected had the best fit to the data, with all terms in the model significantly different from zero and with minimum standard errors of the regression parameters.

Table 5.4: Characteristics of 72 teak sample-trees used to develop volume equations.

Variable	Mean	Standard Deviation	Minimum	Maximum

Height (Ht, m)	13.7	3.08	6.4	20.2
Diameter at breast height (DBH, cm)	12.9	4.63	5.5	29.6
Diameter at centroid height (DCH, cm)	10.8	3.75	5.2	23.0
Centroid height (CHt, m)	4.01	0.90	1.88	5.92
Bark thickness at breast height (BT, mm)	5.4	0.86	3.5	8.0
Tree (centroid) volume (Vol. (total), m^3)	0.0956	0.1060	0.0074	0.5310

Sample Plots

A series of permanent inventory plots (usually arranged as paired-plots) were established in 2009 and 2010 in woodlots owned by smallholder farmers in the Luang Prabang province (as described in the previous section). Every tree in each plot was measured for diameter at breast height over bark (DBH) to nearest 0.1 cm, and total tree height (Ht) to nearest 0.1m using a Vertex hypsometer (as described above). The initial diameter (DBH) and height (Ht) data from these plots (i.e. prior to thinning) were used to estimate the following stand characteristics:

- stems per hectare (i.e. stocking) – count of the number of stems per plot, divided by the plot area (SPH, stems ha^{-1});
- basal area – sum of the cross sectional areas of all stems in a plot, divided by the plot area (BA, m^2 ha^{-1});
- pre-dominant height – taken as the mean of the tallest 50 trees per hectare, i.e. in this case the mean of the tallest 2 or 3 trees per plot (PHt, m); and,
- stand (total) volume – sum of all the estimated tree volumes (as determined using the best fitting equation) divided by the plot area (SVol, m3 ha^{-1}).

Data Analysis – Stand Volume Equations

Individual tree data from a total of 3,448 stems in 76 plots were included in the analyses – two plots were eliminated from those listed in the previous section because of problems with the height measurements (i.e. heights were recorded only to nearest 0.5m) which made it impossible to accurately identify the tallest trees per plot when calculating the pre-dominant height of these two plots.

As indicated in the previous section, plot-level statistics were calculated from the individual tree data for each of these 76 plots (Table 5.5). Regression analysis of these plot-level statistics was used to develop the best fitting volume equations (with all parameters significant, and with minimum standard errors on the regression parameters) to predict stand volume per hectare using PROC REG in the SAS statistical package. The stand volume was estimated by summing the volume of each tree and then dividing by the plot area, using the best fitting equation for estimation of tree volumes.

Table 5.5: Summary of plot-level statistics for the 76 permanent inventory plots used to develop equations to predict stand volume in smallholder teak woodlots.

Variable†	Mean	Standard Deviation	Minimum	Maximum
Age (years)	10.4	3.6	3	16
Diameter (DBH, cm)	11.5	4.37	1.0	31.6
Height (Ht, m)	13.0	4.10	1.3	23.6
Plot area (m^2)	299	5.2	136	324
Stocking (stems ha^{-1}, SPH)	1537	475	555	3086
Basal Area (BA, m^2 ha^{-1})	17.7	6.36	2.50	31.1
Pre-dominant Height (PHt, m)	16.8	3.62	6.7	23.5
Stand Volume (SVol, m^3 ha^{-1})‡	109.8	53.6	5.6	236.5

†Diameter and height statistics are for individual trees, all other variables are plot-level statistics.

‡The volume of each tree was first estimated using individual tree volume equations based on tree diameter and height, as described above – refer results for model.

5.1.4 Site Index Models

Plot level data collected at the establishment of each plot was used to develop site index models for young teak in Luang Prabang Province and to quantify stocking, and productivity of smallholder teak woodlots in this region.

Models to estimate site index were developed using the plot mean heights and plot predominant heights estimated from data collected prior to imposing the thinning treatments on the plots. The natural log of the plot mean and predominant heights were regressed on the inverse of plot age to estimate regression coefficients β_0 and β_1 in the following equation:

$$\ln(Height) = \beta_0 + \beta_1\left(\frac{1}{Age}\right)$$

where 'Height' is either plot mean height or plot predominant height in metres, and 'Age' is age of the plot in years (as estimated by the farmer). A base-age of 15 years was selected for modelling height, as this was close to the oldest data available (maximum was 16 years) and had a reasonable number of plots of this age (12 out of 76 plots for which data were available). Further, at 15 years, mean height was equal to plot age (i.e. 15m) as estimated from the regression model above. Using the estimated parameters β_0 and β_1, this leads to a site index models for mean height and predominant height as follows:

$$SI = \exp\left[\beta_0 + \beta_1\left(\frac{1}{Height}\right)\right]$$

where ‘Height’ is the mean or predominant height of a stand at 15 years, and ‘SI’ is the predicted site index at 15 years (i.e. the selected base age). To estimate site index at other ages, the following formula was used:

$$SI = \exp\left[\ln(Height) + \beta_1 \left(\frac{1}{A} - \frac{1}{A_1} \right) \right]$$

where, ‘SI’ it the site index at a base age (‘A’; here 15 years), and ‘Height’ is the measured mean or predominant height at a different age (‘A_1’). The regression coefficient ‘β_1’ is the same as in the previous two equations.

5.2 Agroforestry Systems Research (Objective 2)

As originally proposed the research into agroforestry systems involving teak was to focus on mixtures of teak and paper mulberry (po sa). Original scoping studies and investigations during the development of the project proposal indicated that sale of bark from po sa provided good returns to smallholders, and that it was possible to grow po sa in mixtures with teak. However, during the intervening period, there was substantial reduction in the price paid to farmers for po sa, accompanied by increase in price of labour, such that the production of po sa became marginal. Consequently, when we began negotiations with farmers in 2008 in relation to setting up experiments integrating po sa as a companion crop with teak, we found no support from farmers for the original proposal of underplanting teak into thinned teak woodlots. Therefore, this component of the research program was not implemented.

Research as implemented included two components:

1. Establishment of a Nelder wheel with alternate spokes of teak and paper mulberry
2. Establishment of agroforestry trials in collaboration with smallholder farmers at Ban Phonsavang (10 sites), involving wide-spaced teak and a range of companion crops as selected by the individual farmer.

The first component of this research failed – we were not able to successfully established po sa with teak in the Nelder wheel planted at Thong Khang (Agroforestry Research Station) in 2008. Despite intensive weed control, the po sa completely failed twice and was replaced by teak in 2010. The primary reasons for the failure of po sa on this site appear to be: susceptibility of po sa to termites when young; moisture stress on the site selected for the trial; and possibly poor nutritional status on this site that had been cropped repeated for a number of years prior to planting the trial. This component of the research will therefore not be reported further.

The second component of this research was added as replacement to the originally proposed concept of interplanting po sa into existing teak plantations following thinning. Discussions with farmers and community groups indicated no support for interplanting po sa into existing teak, plus as we explored the implementation of the concept a number of logistical difficulties became apparent, including: exclusion of grazing animals for isolated small pockets of po sa within teak woodlots; and the difficulty of establishing po sa within established teak woodlots due to the prevalence of termites in most teak stands and the likelihood of moisture stress induced through water extraction by the established teak trees.

Farmers in the Ban Phonsavang village had been the intended primary focus of this component of the research due to their long history of growing po sa (from an earlier World Vision project), and village discussions and field visits indicated that many farmers were already experimenting with mixtures of teak and companion crops such as banana, po sa and broom grass. Many farmers also indicated strong interest in exploring teak agroforestry systems, and offered land for establishment of new teak in mixtures with various companion crops. Subsequently, trials were established in six sites in 2009 and an additional four sites in 2010.

5.2.1 Background

The village of Ban Phonsavang is located approximately 5 km south of the Northern Agriculture and Forestry Research Centre (NAFReC) at Houay Khot in the Xieng Ngeun district of Luang Prabang province. A series of villages meetings were held, in which the objectives of the project were explained, as well as the potential benefits that may result from improved management of teak plantations. This village has had a long involvement with a World Vision project on establishment and management of paper mulberry (po sa) plantings. Due to the history of planting both teak and paper mulberry in the areas surrounding this village, we had anticipated an interest in growing mixed stands of paper mulberry and teak. However, following discussions with village leaders, and outcome of village meetings, it became clear that the farmers were interested in experimenting with a range of companion crops, and were in fact already doing this. Mixed plantings of teak with both banana and paper mulberry are quite common. Therefore, we made an open invitation for farmers interested in testing teak plus paper mulberry, banana or other potential companion crops. The project provided teak stumps at no cost to the farmer, while the farmer provided land, prepared sites and assisted with planting of the teak. Planting of the companion crops and all follow-up weed control and any other maintenance was conducted by the farmer.

Plantings were at various locations around the village, with some being up to a one hour walk away (see Table 5.6, Figure 5.6). Elevation, slopes and aspects were variable. Prospective sites were inspected by project staff, and the most suitable sites were selected following further discussions with both the owners and village leaders.

Site history was variable. Sites are likely to have been used predominantly for the production of upland rice with associated fallow cycles. Many were cleared and burnt in early 2009 or 2010 in preparation for establishment of a variety of crops, at the start of the wet season (i.e. April/May). Specific site history is described further below.

5.2.2 Design and trial establishment

Planting design varied due to the differing site conditions, requirements and requests of the farmers who collaborated in these trials. Further, as these trials will primarily to demonstrate alternative methods of teak cultivation (in contrast to the typical highly stocked monoculture plantations of teak), replication of different treatments within each site was neither practical nor necessarily desirable. A brief description of each design by landowner is presented in Table 5.7. The trials were planted in either May–June 2009 or May–June 2010. Most trials used paired rows of teak planted along the contours (Figure 5.7).

Weeding and maintenance at each site varied and reflected the associated land use. For example, at newly cleared sites where upland rice varieties and Job's tears were cultivated, intensive weeding associated with these crops meant that the teak stumps were not be overgrown by weeds. At other sites where crops such as bananas were already established, or where companion crops were allowed to regenerate naturally after clearing (e.g. broom grass and paper mulberry), teak stumps were more vulnerable to competition from weeds and/or the companion crop (i.e. existing bananas).

Table 5.6: The sites, landowners and areas of each trial site (as calculated from GPS coordinates using Arcview and Google Earth, and from village records). Sites 1 – 6 were planted in 2009 and sites 7 – 10 were planted in 2010. Colour codes match those used in Figure 5.4.

	Site ID	Smallholders	Arc Area (m^2)	Google Area (m^2)	Area (ha)
	1	Mr Sivone	11,581	11,599	1.16
	2	Mr Sivane	4,111	4,117	0.41
	3	Mr Thong & Mrs Li	6,365	6,375	0.64
	4	Mr Phondee	42,127	42,193	4.22
	5	Mr Khamsone	22,533	22,567	2.26
	6	Mr Khamphet & Mrs Lao	9,924	9,939	0.99
	7	Mr Phoune	5,974	5,983	0.6
	8	Mr Chiep	4,838	4,845	0.48
	9	Mr Deenyai	7,518	7,529	0.75
	10	Mr Chanti	12,648	12,667	1.27

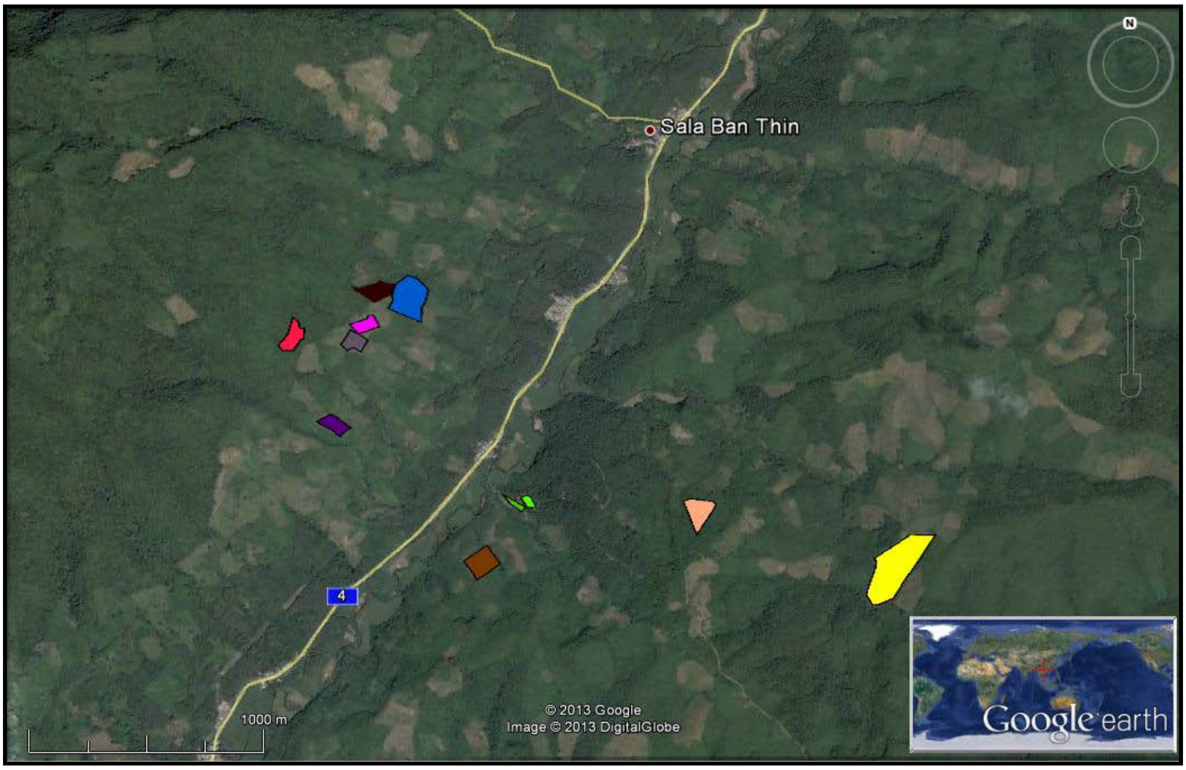

Figure 5.6: Location of Agroforestry trial sites established in 2009 and 2010 around the village of Ban Phonsavang. Colours of each site are as indicated in Table 5.6.

Table 5.7: Planting site descriptions

Site	Owner	Companion crop	Planting description
1	Mr Sivone	Established banana plantation	Mr Sivone's site had fully grown established banana plants planted in rows about 7-8 metres apart. Teak stumps were planted in paired lines between these existing bananas. Ten rows of teak were planted between the banana rows (along the contours).
2	Mr Sivane	Regenerating bananas and paper mulberry. Some rice planted in the upper area above the road.	Mr Sivane's site can be separated into two areas by a dirt road. In both areas teak were planted in paired lines. The first area had been cleared prior to the wet season in 2009 but no rice or intensively managed annual crop was established. Paper mulberry and broom grass were allowed to re-grow and some bananas are present also. Little management occurred. This area is now fenced. The second area is further up the slope and is bounded by the dirt track. In 2009, part of this area was used for growing sticky rice and part was allowed to naturally regenerate similar to the lower area. The upper area was affected by a fire that swept through the lower eastern part of the area. Measure plots were established outside this fire affected area which appeared to have reduced the survival of the teak stumps.
3	Mr Thuong and Mrs Li	Rice and sparse bananas	Five paired lines were planted along the contour, with an 8 metre spacing between the lines. The site had been cleared and a rice crop was grown at the same time as the teak were planted. Some sparse banana plants were also scattered across the site. These were planted about 2 months before the teak and rice. The site is west of the village.
4	Mr Phondy	Rice and jobs tears	Eight paired lines were established along the contour at this upper slope site. Paired lines were spaced 12 metres apart with 516 trees planted in total. The site is about a 45 minute walk up a creek through a valley to the east of the village. The site was cleared and teak were established at the same time as the first post-fallow crop of rice.
5	Mr Khamsone	Rice and sparse bananas	Seven paired rows were established at this site. Two of these rows merged into an upper row so that lines could follow the contour. The site was cleared and teak planted about the same time as the rice. As with site two, some bananas were planted at the site.
6	Mr Phet and Mrs Lao	Bananas and rice (bananas were one year old at time of teak establishment)	This site had already been planted out with bananas previously and the teak plants had been successfully established in lines along the contours. Teak was planted between these existing banana lines two meters apart in single lines (approximate density 600 – 700 sph). Because of this relatively wide spacing only 188 teak plants were planted in this area. The area below the planted site was planted with older banana plants.
7	Mr Phoun	Banana, Job's tears (large grained), and broom grass in first year. No Job's tears in second year.	Five single rows aligned along the contour.

Site	Owner	Companion crop	Planting description
8	Mr Cheab	Job's tears (small grained type), banana planted into site in second year	Five pair rows aligned along the contour, with 6m between adjacent paired rows.
9	Mr Deeyai	Job's tears (both types) plus banana, large grain Job's tears in second year	Five paired-rows, aligned along the contours with 6m separation between adjacent paired rows.
10	Mr Chanty	Banana and Job's tears in first year, bananas only in second year	Six paired rows, aligned along the contours.

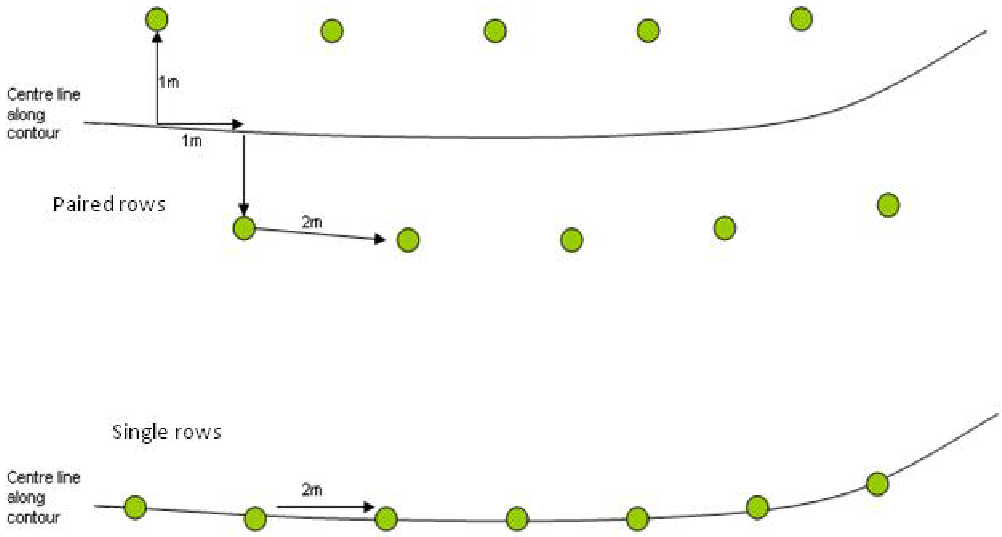

Figure 5.7: Example of the planting design used for of paired (top) and single rows (bottom) of teak. (Teak trees indicated by green circles.)

5.2.3 Planting material

Teak stumps were provided by the project and were sourced from the NAFReC teak stump garden at Houay Khot. Stumps were prepared from one to two year old teak seedlings that were grown from superior seed collected at the Kein Ben Forest Research Station (now closed). These seeds were harvested from a small stand of teak of Myanmar provenance located on the Forest Research Station. Stumps were graded and only suitable planting stock was included (e.g. all stumps were of similar size; oversized, undersized, and damaged stumps were excluded). Each farmer was provided with 500 of these stumps in May 2009, prior to the onset of the wet season. Other planting material (i.e. bananas, paper mulberry etc.) was sourced locally by the participating farmer at their own expense. A similar process was repeated in 2010, for establishment of sites 7-10.

5.2.4 Economic Analysis

Participating farmers recorded the production of annual crops, bananas and the major non timber forest products from each plot. They also recorded prices obtained from the sale of crops each year, allowing gross cash income to be calculated for each plot. In most cases there were limited cash costs involved, with the main costs being family labour.

There are many criteria in which the economics of the agroforestry systems can be evaluated. However, many of these are of limited applicability to semi-subsistence farm households. Gross farm family income (GFFI) is defined as the income received by the farm operator and is calculated as the residual after making actual payments for all expenditures incurred for production inputs, excluding any unpaid return to family-owned resources (land, labour, or capital). In other words, GFFI equals total returns minus paid-out costs and can be viewed as the returns to family-owned resources. The concept of GFFI recognises that the family farm in a semi-subsistence economy is regarded as an indivisible unit managed in the interests of the family as a whole, rather than merely a bundle of factors of production.

We have used the concept of GFFI but called it the net returns to household-owned resources (NRHR). This can be computed per household, per hectare and per day of family labour expended. This last metric (net returns to household labour, NRHL) is particularly useful, given the diversification of household livelihoods through family labour moving into the non-farm sector. NRHL is easily compared to a benchmark wage rate, representing an upper-bound estimate of the opportunity cost of family labour. Evidence that farmers are aware of the opportunity cost of family labour is evident given that households had reduced the collection of paper mulberry once the price dropped because the returns were not sufficient for the amount of labour that was required.

In order to determine the NRHR and NRHL case studies were conducted with participating households. Activity budgets and calendars were developed to determine the returns for various activities and the agroforestry system. The budgeting activities also included the costs of marketing the produce which often included transport costs to Luang Prabang city, market fees and in some cases accommodation. Key informant interviews were also conducted with traders of various cash crops and NTFPs. This also allowed for some sensitivity analysis based on recent prices.

5.3 Teak Genetic Improvement Research (Objective 3)

The research undertaken on the genetic improvement of teak aimed to selected, propagate, test and distributed teak clones to smallholder farmers, using propagation by cuttings of superior trees selected within existing woodlots in Luang Prabang. The first phase of this component of the project sort to propagate teak using cuttings, and in the second phase propagation was via grafting. Initially this was conceived as a farmer-participatory model, but due to difficulty experienced in propagating teak via cuttings this did not prove to be possible. Therefore, the work was divested primarily to staff working at NAFReC.

Construction of new nursery facilities at research partners was delayed, partially as consequence of the late project start date (July rather than May) and partially as consequence of unforseen problems in organising construction. This meant that commencement of this component of the project was also delayed until the new nursery at NAFReC was completed in January 2010. Subsequent difficulties in propagating teak using cuttings meant that it was not possible to establish field trails of selected teak clones during the timeframe of this project.

5.3.1 Propagation by Cuttings

Compared to grafting, propagation of teak using cuttings (if successful) offers a number of advantages. Firstly, there is no danger that the scion will be replaced by vigorous shoots from the root stock as can occur with grafts. Secondly, it is relatively low cost and requires relatively low levels of skill and technology compared to grafting or other propagation methods, and so can be used for production of planting stock by farmers at a cost similar to stumps from seed. Finally, there were some indications that stumps, might be produced from cuttings in similar manner to that used for seedling plants of teak.

Based on recommendations by Olivier Monteuuis (pers. comm. 2009) and his experience in Sabah Malaysia (Monteuuis and Goh, 1999), we elected to propagate of selected (elite) trees using ‘sticks’ rather than coppice shoots. This eliminates the risk that the selected tree might die following girdling. Live branches are collected, and cut into short sticks and set in polybags under a misting regime. These sticks produce sprouts that can then set as cuttings. This technique has been used successfully in Sabah, and although initial rooting success is expected to be quite low, experience in Sabah indicates that serial propagation from the initial rooted cuttings is much more successful.

Nursery Establishment

A dedicated teak nursery was completed at NAFReC in January 2010. This nursery includes a series of concrete beds with a reliable water source and automated water misting system. The nursery was covered in black shade cloth providing about 50% shade. The watering systems includes a concrete water tank with float valve, an automatic water pressure pump, filter, Galcon misting controller and six beds with misting sprayers which can be individually turned on and off. A chlorine injection system was added in mid-2010 to sterilise the water prior to distribution to the propagation beds.

Project funds were also used to upgrade nursery facilities at the Souphanouvong University, to allow propagation of teak. A well and electric pump were installed to provide a reliable water source during 2008/9; nursery beds (in-ground) and high-shade were established during 2009/10. This nursery more closely approximates facilities that may be available at a village level.

Selection of trees and collection of sticks

Trees were selected by project staff in collaboration with farmers from the participating villages. Selection criteria include: relative growth rate, stem form, branching etc. Once selected, the following documentation was collected on each tree: location (including latitude and longitude), diameter at breast height (DBH), height, age (where available) and an overall description of the trees form and position in the plantation. From each selected tree a number of green branches were removed.

Producing sprouts from sticks and setting sprouts as cuttings

Collected branches were cut into lengths (1 or 2 nodes) approximately 30-40cm in length and placed in poly bags. These potted sticks were initially placed under an enclosure covered with opaque plastic (larger shade cloth) and kept moist using the misting system. Sprout production and vigour varied between parent trees although most series of sticks produced at least some sprouts. These sprouts were allowed to grow until 5-8 cm long and then removed and set as cuttings in a separate sand bed (Figure 5.8). This bed was covered by an opaque plastic enclosure and provided with moisture via the misting system. Setting of cuttings commenced in mid-2010.

Figure 5.8: New shoots produced on sticks set under shade (left) and cuttings set in sand beds (right) at Houay Khot nursery December 2010 (Photographs: Mark Dieters).

5.3.2 Propagation by Grafting

Low success rate with propagation by cuttings, led to preliminary experimentation with propagation by grafting on to bare-root stumps, and then growing-on in polybags under shade. Initial work was conducted in 2011/12, and then in 2012/13 as part of the one-year extension of this project (using additional funds provided by Small Research Activity[4]), a total of 100 superior trees were selected and grafted (some of these are the same trees as selected in 5.3.1 above, but unfortunately many had been cut by 2013 or could not be relocated accurately. In order to assemble a diverse sample of elite trees from the Luang

[4] *The final report from this Small Research Activity can be found at: http://aciar.gov.au/publication/FR2014-03*

Prabang teak plantations, and to provide a source of genetically improved teak, trees were selected phenotypically in diverse regions of Luang Prabang province (refer to results). Each selected tree was marked, and geo-tagged using a hand-held GPS, mapped and photographed. Branches were collected from each selected tree just prior to the start of the 2013 wet season, and grafted onto bare-root ‘stumps’ that were when the grown in polybags for 3-4 months in the NAFReC nurseries. The procedures used are illustrated in Figure 5.9.

Figure 5.9: Process of grafting teak onto bare-root stumps. Kikeo Singhalath preparing grafting material and rootstock, April 2013. (Photographs by Somphanh Sakanphet and Kikeo Singhalath.)

5.4 Socio-Economic Research (Objective 4)

The socio-economic research reviewed the underlying incentives for the expansion of teak woodlots and examined the livelihood activities of both teak and non-teak producers. This involved the following activities:

1. Reconnaissance field work,
2. Household survey, and
3. Case studies

5.4.1 Reconnaissance field work

In 2009, key informant interviews were conducted with members of the village committee and farmers. The objective of these surveys was to quickly obtain basic information about the village and livelihood activities to assist in designing and executing the household surveys and more in-depth investigations.

5.4.2 Household survey

In 2009, a survey was conducted of 127 farm households in five teak-growing villages in four districts of Luang Prabang province (Luang Prabang, Xieng Ngeun, Chomphet, and Nan Districts). The five villages were selected to highlight differences in proximity to Luang Prabang city, ethnicity, resettlement history, population density, and other land-use opportunities. The selected villages were Ban Kok Ngiew, Ban Xienglom, Ban Phonsavang, Ban Phatonglom, and Ban Sanok (Figure 5.10).

The purpose of the survey was to understand the various influences on, and the differential impacts of, the adoption of teak planting and improved management by farmers in the province. There is considerable diversity both within and between teak-growing villages in Luang Prabang. This includes diversity in ethnicity, relocation history, access to land resources, alternative farming opportunities (including paddy land and river gardens), road infrastructure and access to markets, access to extension activities (teak and other livelihood projects), and local-level implementation of government policies. It was hypothesised that these factors would all influence farmers' ability to adopt teak production systems and hence give rise to differential impacts of smallholder teak initiatives (including the ACIAR project) on household livelihoods.

Project field staff conducted a structured interview with the household head or an older household member. The questionnaire sought information regarding the household's composition, settlement and relocation history, cropping and livestock activities, the collection, consumption and sale of non-timber forest products (NTFP), off-farm and non-farm employment, access to extension services and other sources of information, access to credit, land transactions, rice self-sufficiency and household assets. For those households with teak woodlots, additional information was sought regarding the number of blocks planted, number of trees, timing of planting, spacing between trees, planting of companion crops and respondent's knowledge of silvicultural practices.

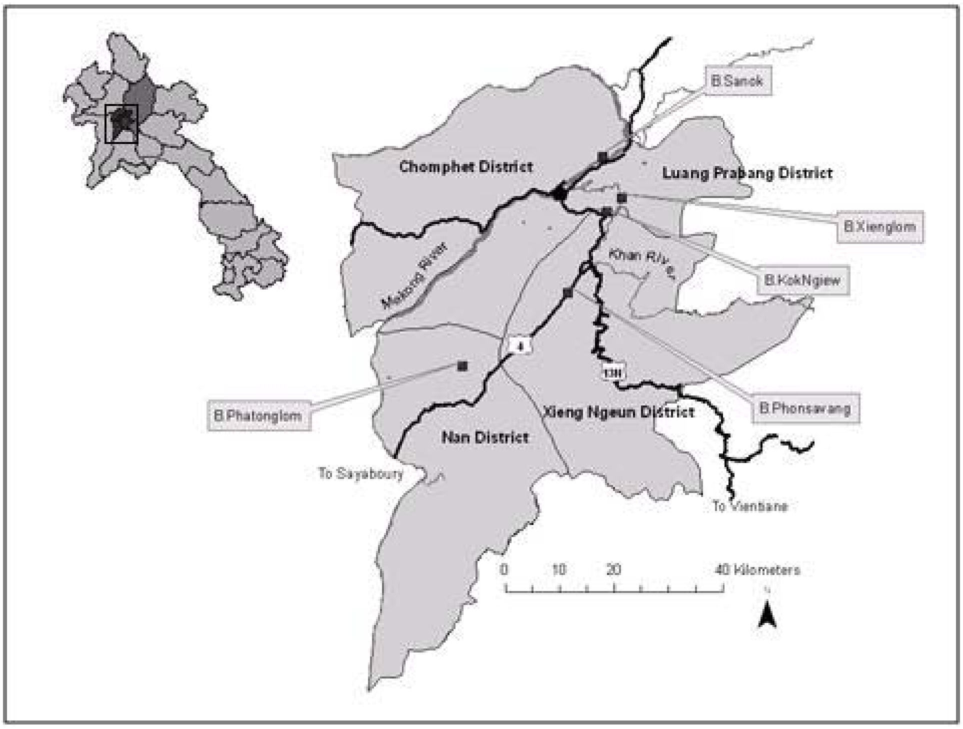

Figure 5.10: Location of case study villages in Luang Prabang Province, northern Laos.

5.4.3 Case studies

From the analysis of the survey data, key households types were identified in each village. This typology focused on each household's most important activities, the most important source of cash income, paddy rice versus upland rice cultivation, rice self-sufficiency, access to cropping and fallow land, and the size and age of teak plantations. The household types varied between villages, reflecting the inter-village variation in livelihood activities (Table 1). An individual case-study household was randomly selected to represent each type. This case-study approach lends itself to understanding the complex relationships between the range of biophysical environments, farming households, and the socioeconomic and political conditions that influence their land-use decisions.

In August 2010, semi-structured interviews and farm walks were conducted with each case-study household. The interviews first established land holdings, tenure, and current land-use of each parcel either owned or utilised by the household. Historical land uses were also recorded for each parcel. Often this meant tracking the use of additional parcels of land that the household no longer owned or had allocated to other family members. The iterative process of looking at activities across years and parcels provided a level of detail of the dynamics of land use that could not be captured using a structured survey. Details of other activities recorded in the initial survey, such as livestock and outside employment, were also confirmed. In addition, the seasonal allocation of labour was obtained using activity calendars, and costs and returns were estimated for key cropping activities.

Almost two years later, in June-July 2012, an additional interview was conducted with each of the case-study households. These interviews focused on changes during the previous two years as well as future plans for each parcel of land and each member of the household. Photographs taken during the first case-study interviews were given to the participants, which provided a useful entry point to discuss changes over the past two years. The village head (ni ban) was also interviewed about changes in the village;

however, his observations were mostly based on subjective impressions as village statistics remained out of date.

6 Achievements against activities and outputs/milestones

Objective 1: To develop improved silvicultural systems for teak, leading to productivity increases through improved growth and form.

Nº	Activity	Outputs/ milestones	Completion date	Comments
1.1	Demonstration trials using Nelder Wheel Design	Annual measure data summarised and reported	2008 – Nelder wheels were established at Northern Agriculture and Forestry College and Agroforestry Research Station (Thong Khang) 2009 – Third Nelder established at Souphanouvong University (SU). Annually – all Nelder wheels measured annually during the dry season (i.e. Dec./Jan./Feb), data collated and validated, and summaries prepared. 2012 – preliminary experiments commenced on intercropping in College Nelder 2013 – replicated experiment established as part of SRA with peanut, cassava, pigeon pea and maize. Initial results are promising (refer separate report). 2013 – new Nelder established at Thong Khang, with greater range of stockings between 400 and 1000 sph.	The College Nelder has been very successful, with excellent growth rates. The Thong Khang Nelder has been problematic from the beginning – suffering from poor survival due to termites (100% of po sa killed twice, and requiring replacement with teak), and poor growth rates related to nutrient deficiency (most probably P). The SU site has suffered as consequence of poor/irregular weed control leading to variable growth rates, plus compaction associated with old track has impacted severely on growth of some trees. Poster paper prepared and presented at the World Teak Conference, March 2013, Bangkok. Results to the end of the 5th growing season demonstrate that optimal growth rates are achieved by much lower stocking rates (i.e. 600 sph) than currently recommended (i.e. 1100 sph).
		Field days conducted	Field days conducted at the in 2009 and 2013 – representatives from farmer groups, DAFO/PAFO attended field days at College Nelder.	Generated considerable interest and discussion in 2013, as now there are strong trends clearly visible in the growth/form of teak as related to the initial stocking. Will provide excellent research and demonstration tool as trials age. Nelder at Souphanouvong University is still viable. At least part of this will be useful demonstration tool.

1.2	On-farm thinning trials	Thinning completed. Establishment report written	2009 and 2010 – Network of thinning trials established across the first two years of the project, and establishment report completed. Thinning treatments imposed in 2009 or 2010 – plots were remeasured annually during the dry season through to 2012. Only a subset of the better trial sites were remeasured in 2013 (i.e. sites intended for retention into the new project).	Thinning treatments were randomly allocated to one of each paired plot at each site, and removed up to approximately 1/3 of the standing trees in each treated plot. In most cases it was not possible to achieve target residual stocking of 800 sph (or less) as farmers were reluctant to move the number of trees required when the initial stocking rates were very high (i.e. over 1200 sph).
		Annual reports written	Data were collated and validated annually, and analyses updated. Final report and publication of results is still in draft stage. Overview of results presented to final project workshop in June 2013.	Analysis of accumulated data is complex due to variation between sites in stocking and age at the time of thinning. However, we are now much more confident about the appropriate interpretation of these results, and will move to development of extension materials and publication in appropriate media.

Objective 2: To develop improved management systems for mixed species plantations involving teak and commercial non-timber forest products.

No.	Activity	Outputs/ milestones	Completion date	Comments
2.1	Demonstration trials using Nelder Wheel design	Annual measure data summarised and reported	Paper mulberry (po sa) was incorporated into the Nelder wheel planted at Thong Khang in 2008. Replanting of the paper mulberry occurred in 2009/2010.	This component of the project was terminated in 2010. The paper mulberry proved to be very susceptible to termites on tis sites. Therefore, the paper mulberry was replaced with teak in the Nelder wheel.
2.2	On farm thinning trials - paper mulberry under-plant, and teak into existing paper mulberry stand	Annual reports	Not completed. Terminated in 2009/10. Agroforestry trials planted in 2009 and 2010. Agroforestry trials remeasured annually, and results summarized.	Following discussions with project partners and potential collaborators, we found no interest amongst farmers in removing teak and replacing with po sa, and so terminated with approval of RPM. This component was replaced with ‘agroforestry trials’ where new teak plantations were established with range of companion crops of interest to the farmers. Trials have now be established on 10 sites.
2.3	Agro-forestry trials	Annual reports	Data analysed and report summarising both growth data and returns from the companion crops will be completed for publication.	All sites have been documented, measurements conducted annually. Returns from the companion crops are now tapering-off, so provide logical point to complete detailed write-up and publication of these results. Next stage will involve thinning of teak, and potentially establishing new crops in the inter-rows.

Objective 3: To develop capacity to generate and deploy improved teak germplasm at the village level.

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Identify and propagate elite teak trees	Hedges established at university and forest research station	2009/10 – new nursery established. 2010/11 – fifty trees selected, branches set under mist, cutting set, but very poor rooting. 2011/12 – commenced preliminary work on using grafting as alternative. 2012/13 – selection and documentation of 100 plus trees, and propagation by grafting.	Delays with the construction of the nursery at NAFReC and SU pushed this work back at approximately 12 months from originally planned. Propagation of teak by cuttings from shoots produced on 'sticks' proved very difficult. Less than 10 rooted cuttings were produced. This was probably at least partially due to very high pH of water supply to the nursery. Initial grafting experiments had very high success rates (>70%), however identities of clones lost due to mix-up in nursery. Grafting work funded under separate SRA. Grafts planted into clone bank and seed orchard. Potted grafts retained for uses as hedges, and some transferred to the Agriculture Research Center (Naphok, near Vientiane for tissue culture research).
3.2	Establishment and assessment of farmer-participatory trials of elite trees	Participating farmers surveyed to determine level of interest. Training provided.	Not completed.	This component of the project has not been possible. Delays in propagation of teak using cuttings, meant that clonal material were available for on-farm trials within time-span of the current project.
		Trials established on farms, and documented. Trial assessed and reported	Not completed.	See above.
3.3	Distribute germplasm	Best trees selected and nursery training provided	12/2011	Nursery training provide in 2009/10 to project participants. See above. Slow progress in propagation of teak clones by cuttings, will mean that it is not possible to distribute clonal material in the course of the current project.
		Genetic material of best trees distributed	Not completed	See above. This component has been moved into new project to start in 2013 using clones propagated from the grafted trees.

Objective 4: To develop economically profitable agroforestry systems involving teak.

No.	Activity	Outputs/ milestones	Completion date	Comments
4.1	Survey of current circumstances and practices of teak smallholders in LP area.	Survey completed; Data analysed; Report produced.	Surveys completed in 2009 of households. Published as conference paper and journal article.	Surveys completed in villages selected from among those that we are working in for other components of this project. Villages selected to be contrasting in demographics and income. Householders interview from a broad cross-section of each village, including household with/without teak woodlots.
4.2	Case studies of farm-types	Fieldwork completed Data analysed Report produced	2010/11 – completed interviews of individuals selected from the household surveys.	Individuals selected to represent different development pathways, using information provided in the initial household surveys.
4.3	Rapid survey of relevant commodity markets	Market report	08/2010	Surveys completed.
4.4	Development of farm financial models	Key informant interviews Report	2011-13 – finalized interviews with informants in 2013. Greater focus on agroforestry systems as project developed compared to thinning of existing woodlots.	Initially we aimed to focus on evaluation of thinning and growth responses. However, as there were not clear growth responses in first two-three years after thinning, it has not yet been possible to complete economic evaluation of thinning options. We anticipate that adequate information will be available to do this in the first year of the year project. Further, it became clear as the project developed that monocultures of teak were not viable development pathway for many resource poor farmers. Therefore, refocused this work on the economics of the agroforestry systems applied in new component (see 2.2. in table above.)

7 Key results and discussion

7.1 Teak Silviculture Research (Objective 1)

7.1.1 Nelder Wheel – Northern Agriculture and Forestry College

Here we report on results from the first Nelder wheel that was established in 2009 on the campus of the Northern Agriculture and Forestry College at Pakxuang. Data were also collected annually from Nelder wheels established at the Agroforestry Research Station (Thong Khang) in 2009 and Souphanouvong University in 2010. However, the growth of the Nelder at Thong Khang has been very poor; most probably attributable to history of continuous cropping on this site prior to establishing the teak leading to nutrient deficiencies therefore results are not reported. Growth of the teak trees in the third Nelder wheel at Souphanouvong University has been uneven as consequence of inadequate weed control during the first two years after planting, and compaction along a pre-existing track located through the Nelder. Due to these complications, results are also not presented here. By contrast, the Nelder wheel planted at the Northern Agriculture and Forestry College is on a high-quality site, and the weed-control during the establishment phase has been excellent, resulting in 100% survival, and uniform growth response across the experiment. Data collected through to 2012/13 (i.e. end of the 5th growing season) is reported here.

At the end of its 5th growing season, the College Nelder wheel has provided evidence to suggest that an initial stocking of between 600 to 800 stems per hectare would optimise early growth (when considering girth, height and tree volume) of teak. Significant reductions in girth and height increments at higher stocking rates observed in the 5th growing season suggest that where an initial stocking of 1000 sph or higher is used, first (non-commercial) thinning should occur by 6-8 years after planting (depending on initial stockings and site quality) in order to maintain growth rates (and hence returns to smallholders) and avoid adverse effects of inter-tree competition which can lead to suppression and ultimately mortality.

Key Results and Discussion

Over the first three years after planting it was observed that the local Luang Prabang teak had performed slightly better than the Myanmar source, possibly reflecting differences in the quality of planting stock. However, by the fifth season after planting no significant differences in growth were recorded between these two provenances (9.61m (M); 9.65m (LP)), and there were no significant spacing by provenance interactions. Therefore provenance effects have not been included in the analysis for this report.

Increases in tree height across all stocking categories were generally uniform during the first two years after establishment, with no significant differences observed. This can be attributed to the small size of young saplings (height and crown size) in relation to the initial spacing. In years 3 and 4, higher stocking (2,424 sph) favoured greater increases in height compared to trees in the lower stocking rates (106 sph) of the Nelder wheel. An average of 1.5, 4.2, 8.2 and 9.6m in height were recorded by the end of the second, third, fourth and fifth growing seasons respectively.

An average annual increment in height (mean annual increment) of 3.5m was achieved within the higher stockings of the Nelder wheel in the 4th year. However, growth rates fell to 2.5m by the 5th year and were maximised (approx. 3m) at a stocking of 423 sph (Figure 7.1). Trends suggest that height increments will continue to maximise away from the centre of the Nelder wheel (into lower stocking) over the coming years.

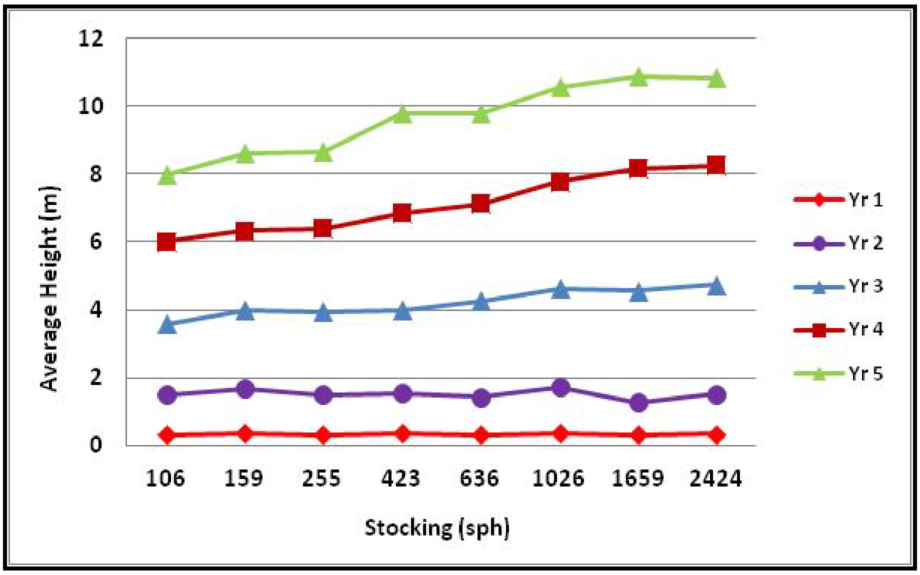

Figure 7.1: Average height of Teak (*Tectona grandis*) during the first 5 years at various stocking rates within the Nelder wheel situated at the Northern Agriculture and Forestry College.

Girth was not greatly influenced by initial stocking rates until the fourth year after planting, with no significant differences observed. By the 3rd year girth began to maximise at around 1020 sph (Figure 7.2), but differences were small. And by the 4th and 5th year, girth maximised at lower stocking rates (around 636 sph). By the end of the 5th year, girth was lowest at either end of the stocking spectrum, suggesting that crown exposure to either competition from neighbouring trees for space and light (at the centre of the wheel) or the impact of environmental factors such as wind (at the outside of the wheel) hinder growth. The results suggest that an initial stocking less than 1000 sph and greater than 600 would provide adequate space to maximise stem development through to around 5-6 years after planting.

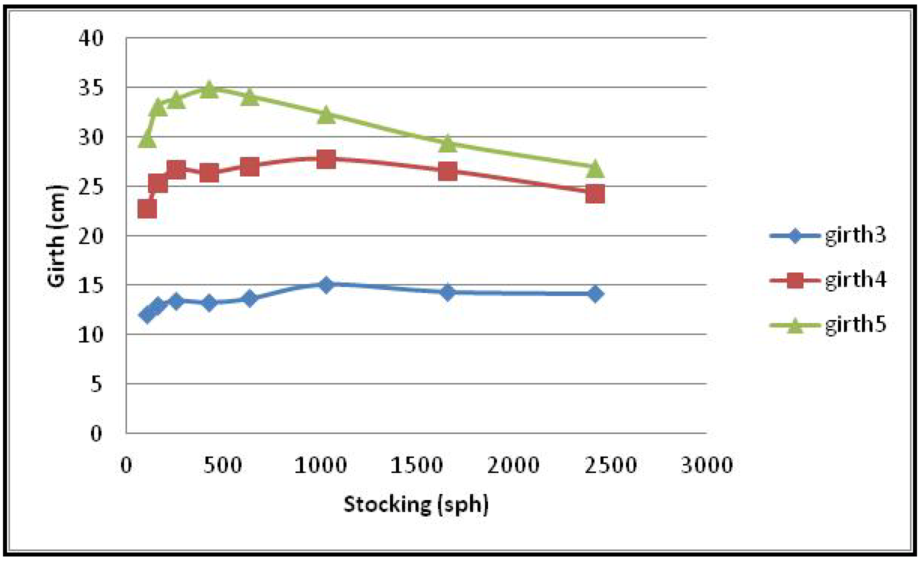

Figure 7.2: Average girth of teak (*Tectona grandis*) at the ages 3 to 5 years at the various stocking rates within the Nelder wheel situated at the Northern Agriculture and Forestry College.

Average annual increments in girth were at their optimum at stockings of between 255 and 636 sph in the 4th year and at their lowest level at either end of the stocking spectrum (Figure 7.3). Growth in girth in the 5th year had diminished across the entire stocking range in comparison to the previous year, with the largest reduction in growth occurring at the higher stocking. Growth in tree girth appears to be optimum towards the lower end of the stocking spectrum, which demonstrates the negative impact of high stocking on tree growth at this age. This result suggests that smallholders with plantings stocked over 1,200 sph, should consider thinning well before growth rates start to decrease from overcrowding (i.e. before 6-8 years after planting). Such a thinning would automatically transfer the formation of new timber into the remaining trees, thereby maximising girth increments on the largest trees in the stand.

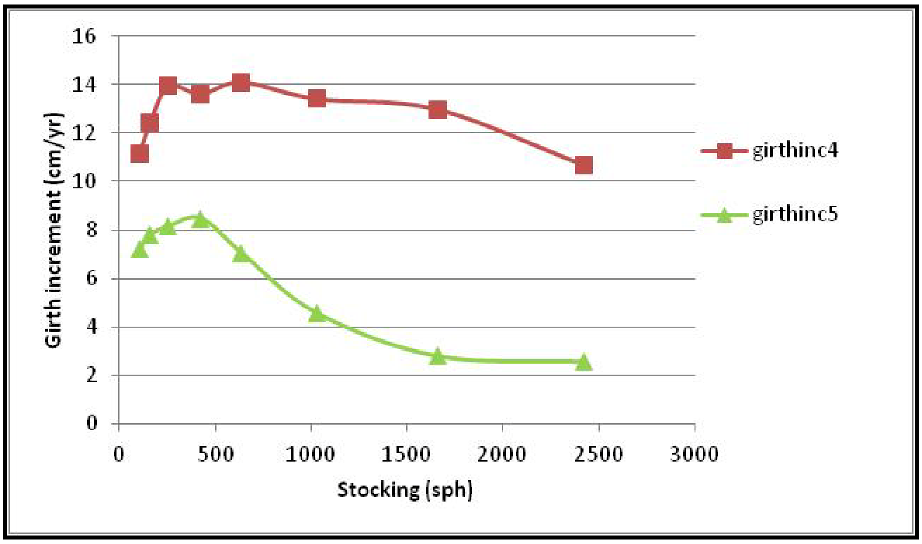

Figure 7.3: Annual girth increment (cm/yr) for teak (*Tectona grandis*) in years 4 and 5 at various stocking rates within the Nelder wheel situated at the Northern Agriculture and Forestry College.

Opposite relationships were observed for girth and tree height across the stocking range in this Nelder wheel at the end of the fifth growing season (Figures 7.2-7.4): growth in tree height was maximised under higher stocking, while growth in girth was maximised at lower stocking. From these results it can be observed that near optimum growth could be achieved in both height and girth at an initial spacing of between 400 and 1,000 sph is adopted.

As previously mentioned, at the end of the 5th year both girth and height were maximising at either end of the stocking spectrum (Figure 7.5; (girth, R^2=0.89; height, R^2=0.96)). The annual increments in girth at the end of the fifth growing season were greatly influence by initial stocking (Figure 7.6; R^2 = 0.95). At this age, the increment in girth (8.5 cm/yr) was optimised at lower stocking, while there was significantly lower growth (2.5 cm/yr) at the higher end of the stocking range. Annual growth in height was optimised at around 1,200 sph at this age (5yrs) and diminished within the higher stocking range most probably because of the competition for space, light, soil nutrients and moisture. During the next few seasons, growth in height will probably optimise in the lower range of stocking (<600 sph).

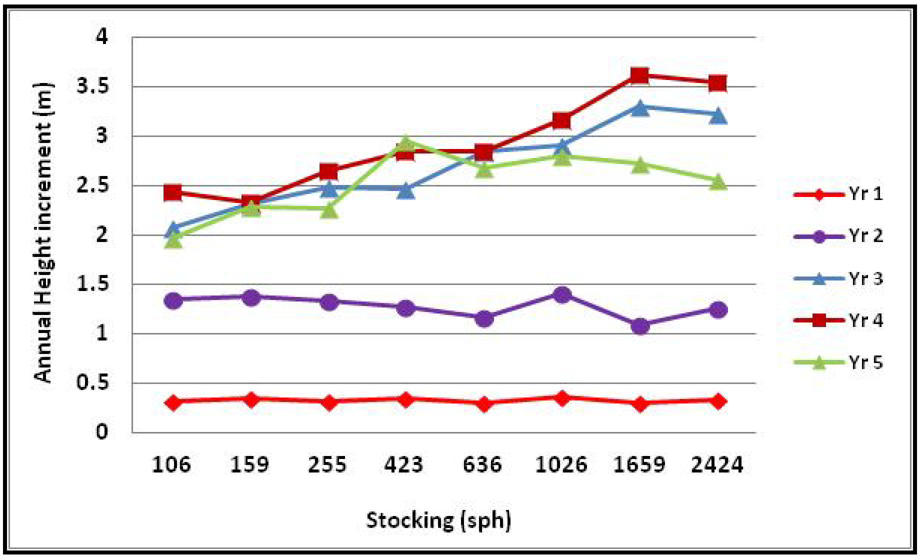

Figure 7.4: Mean annual height increment of teak (*Tectona grandis*) over the first 5 years at various stocking rates within the Nelder wheel situated at the Northern Agriculture and Forestry College.

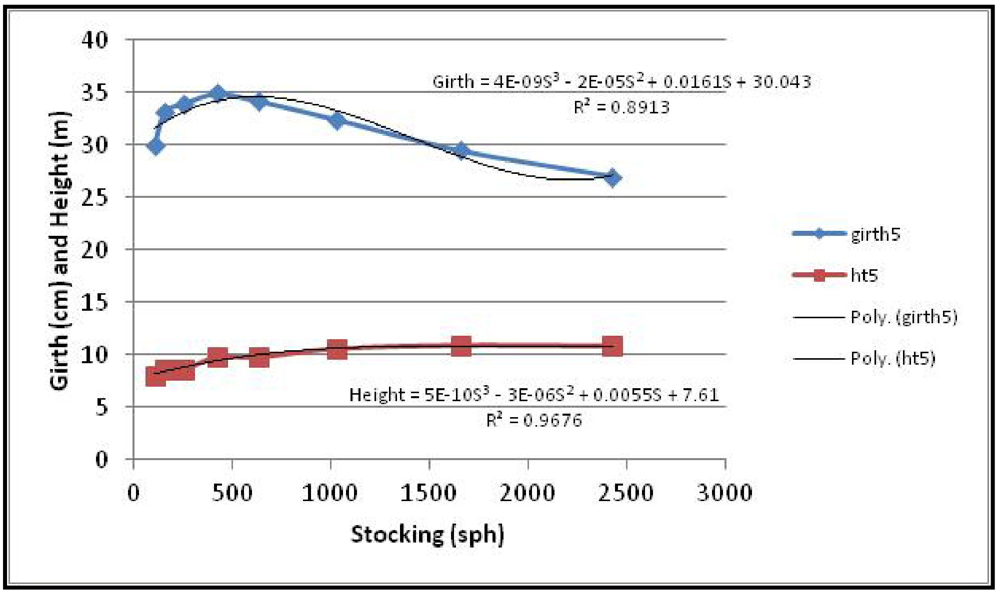

Figure 7.5: Third order polynomials for mean girth and height at the end of the fifth growing season, indicated a strong relationship with stocking (S = stocking in stems per hectare).

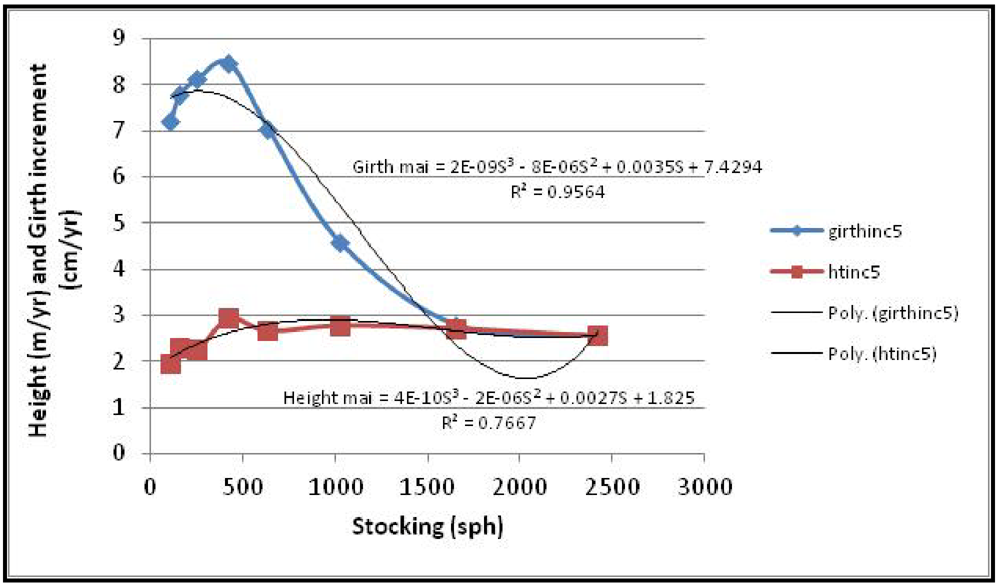

Figure 7.6: Third order polynomials for mean girth and mean height increments at the end of the fifth growing season, indicated a strong relationship with stocking (S = stocking in stems per hectare).

Tree volume (dm^3/tree) is a function of girth and tree height (Figure 7.7). At the end of the 3rd growing season, tree volume across the stocking ranges showed no significant differences across the stocking levels. However, after the following two growing seasons, the impacts of stocking on tree volume became evident. With an initial stocking of less than 400 sph, during this period (4-5 years after planting) increases in volume were possibly restricted because of tree exposure to the effects of wind and sun. At the other end of the stocking gradient (above 1,000 sph) tree volume was suppressed, most probably because of high inter-tree competition (Figure 7.7). By the end of the 4th growing season tree volume was maximising at a stocking of around 1,000 sph, while by the end of the 5th season, tree volume maximised at less than 600 sph. It is expected that at the end of the 6th growing season tree volume will maximise at even lower stocking, reflecting the interaction between tree growth and stocking.

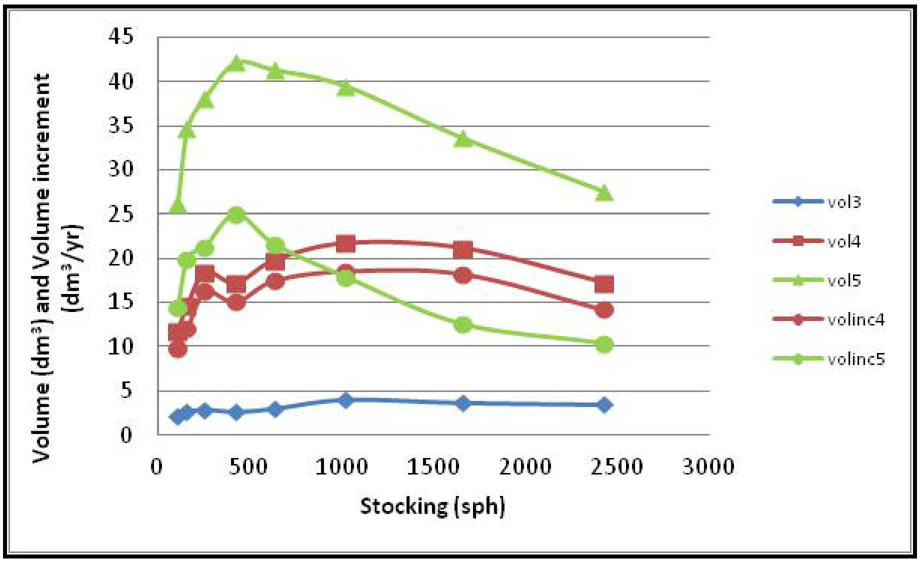

Figure 7.7: Average tree volume (dm^3) and annual volume increment (dm^3/tree/yr) at the end of the third (only volume), fourth and fifth growing season (Northern Agriculture and Forestry College).

7.1.2 Volume Equations

Sample trees ranged from 5 to 30 cm in diameter at breast height, and over this range demonstrated a strong relationship between the measured diameter and height of each tree and the tree volume (Figure 7.8) estimated by the centroid method. This diameter range is similar to that observed in the inventory plots, and therefore it is reasonable to assume that the tree-volume equations can be appropriately applied to develop stand-volume equations using the data from these inventory plots.

Strong linear relationships exists between both DBH-squared (D2) and D2 × tree height (D2H) and tree volume (Figure 7.8) as is to be expected due to the contributions of both diameter and height to estimation of tree volume. Two models were developed to predict the volume of individual trees, one based on diameter and the other on diameter and height (Eqns. 1 and 2; Table 7.1). In both cases the intercept term was not significant, and would not be biologically meaningful if included (i.e. volume should be zero when either diameter and/or height are zero). Note that the inclusion of π/40,000, in Equations 1 and 2, converts diameter-squared (cm^2), to cross-sectional area (m^2). Cross-sectional area x height is the volume of a cylinder, and so the coefficient in Equation 2 of 0.423 is equivalent to the form factor as defined by Van Laar and Akça (2007, p. 71), indicating that the tree volume of teak trees is approximately 42% of a cylinder of the same diameter and height.

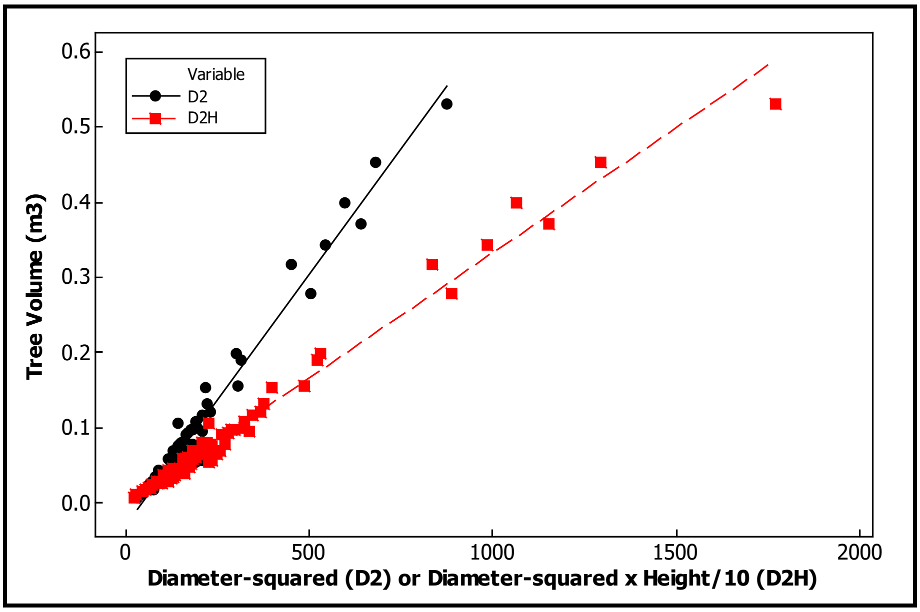

Figure 7.8: Relationship between tree volume (y-axis) and both diameter-squared (black circles; DBH x DBH), and diameter-squared by height (red squares; DBH x DBH x Ht/10) for teak in smallholder woodlots of northern Laos.

The only comparable tree-volume equations that could be found for teak in the published literature are for total volume of teak grown in Costa Rica (Perez and Kannienn, 2003; Perez, 2008). These two models use diameter to predict the volume of individual trees over-bark, in contrast to models presented in Table 7.1 which estimate tree volumes under-bark. When these two models are compared to Eqns. 1 and 2, the equations which do not include tree height (i.e. Eqn. 1 and the two models for Costa Rica) yield lower estimated volumes than Eqn. 2 below diameters of 16-18cm, and substantially higher volumes above 20cm (Figure 7.9). The two over-bark models provide much larger estimated volumes than our two under-bark models (Figure 7.9), as would be expected. Interestingly Eqn. 1 and the two models for teak in Costa Rica are very strongly correlated (r = 0.999), suggesting that plantation grown teak in northern Laos and Costa Rica have a very similar form.

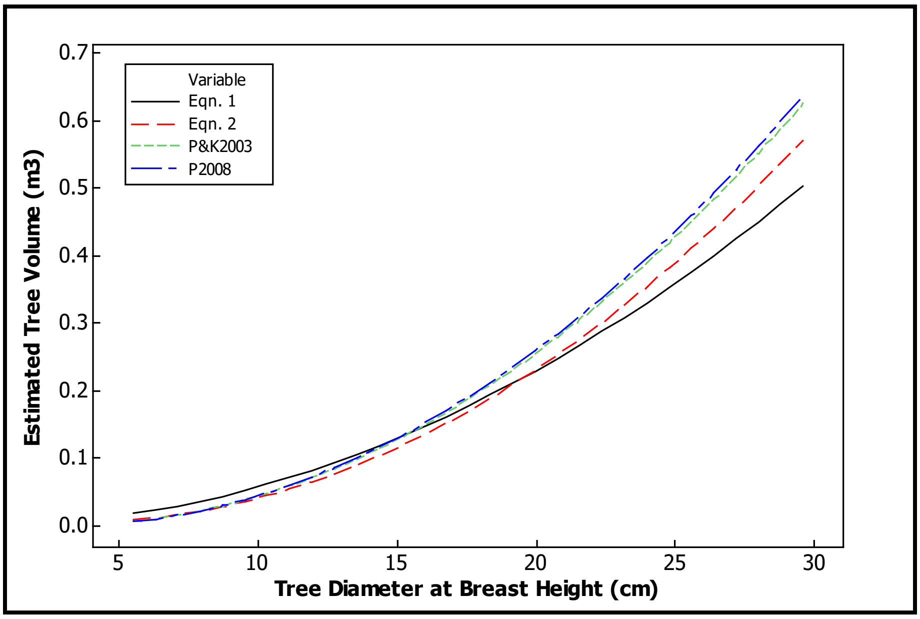

Figure 7.9: Estimated tree volume across diameter range using Equations 1 and 2 (volume under-bark), and tree volume equations for teak in Costa Rica (over-bark) published by Perez and Kanninen (2003; P&K2003) and Perez (2008; P2008).

The standing volume of each plot was estimated using Equation 2 (Table 7.1) as indicated in the methods. The estimated volume of each plot showed a strong linear relationship with basal area multiplied by predominant height (Figure 7.10), and this proved to be the best predictor of stand volume (Eqn. 4, Table 7.1). Nevertheless, if basal area alone is used to predict stand volume, the derived equation provides only a slightly poorer fit (Eqn. 3, Table 7.1), but may still be useful when equipment is not available to accurately measure tree height. However, if the estimated volumes are compared to the actual measured volumes, the equation which does not include stand height (i.e. Eqn. 3), provides higher estimates when volumes are low (i.e. below 100 – 125 m^3 ha–1) and lower estimates above around 150 m^3 ha–1 (Figure 7.11).

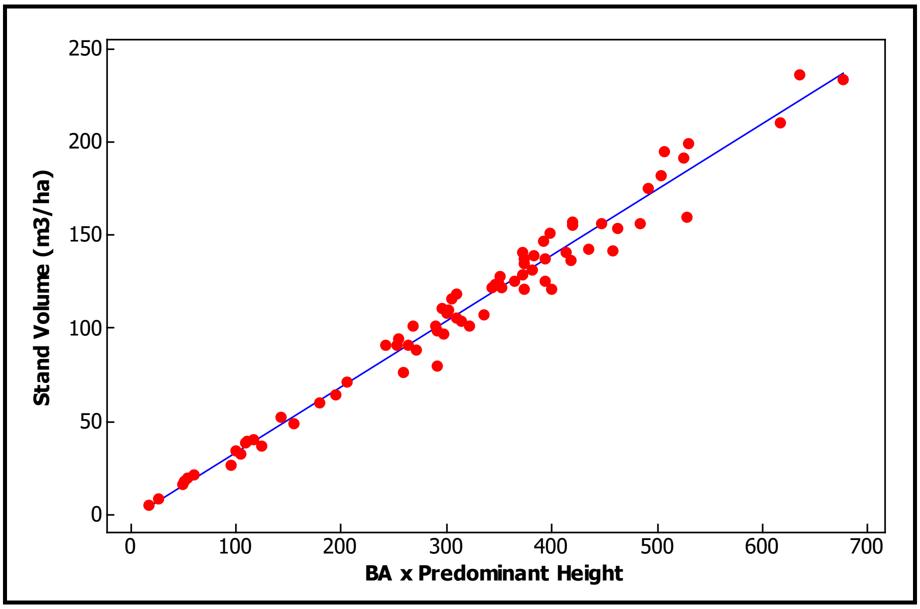

Figure 7.10: Relationship between stand volume (y-axis; m^3 ha^{-1}) and Basal Area (m^2 ha^{-1}) × Predominant Height (m), for teak growing in Luang Prabang Province, Laos.

Table 7.1: Best fitting equations to predict tree and stand volumes for teak in Luang Prabang Province.

Equation Nº	Type of Equation	Equation†	R^2	Standard error of Coefficient
1	Tree	$Vol = 7.314\pi(DBH)^2 / 40{,}000$	0.967	0.160
2	Tree	$Vol = 0.4230\pi(DBH)^2 Ht / 40{,}000$	0.990	0.0049
3	Stand	$SVol = 6.4782 \times BA$	0.978	0.114
4	Stand	$SVol = 0.34813 \times BA \times PHt$	0.995	0.00284

† Vol = total tree volume under-bark (m^3), SVol = stand volume under-bark (m^3 ha^{-1}), DBH = diameter at breast height (cm), Ht = tree height (m), BA = Basal Area (m^2 ha^{-1}), PHt = Predominant Height (m).

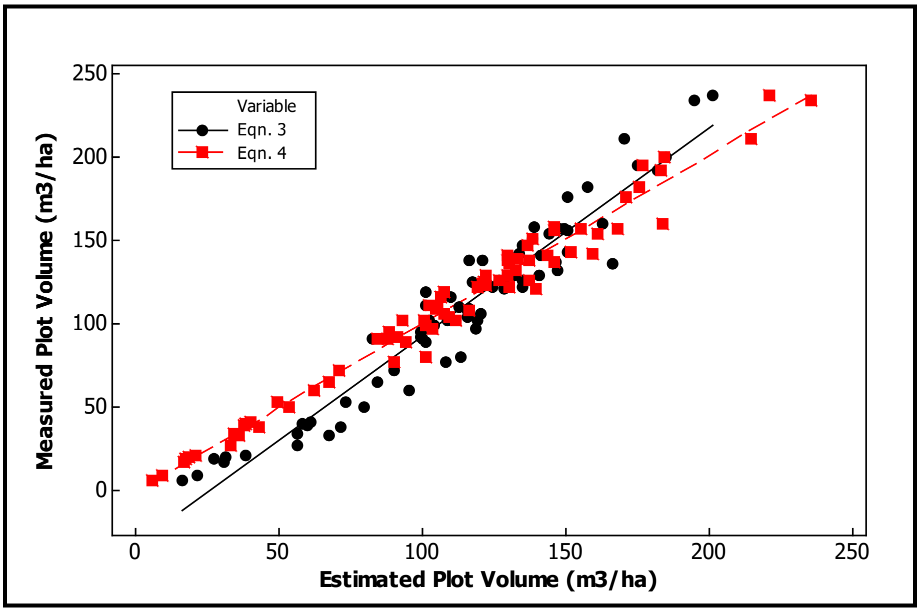

Figure 7.11: Plot volumes (m^3 ha^{-1}) estimated using Equations 3 and 4 (Table 4) compared to the plot volumes measured in the permanent inventory plots (Tables 2 and 3).

The volume equations presented here, provide accurate estimates of both tree and stand volumes, and are suitable for estimation of volume in young teak woodlots (with maximum diameters up to approximately 32 cm), grown in the Luang Prabang province of northern Laos. These equations can be used to estimate the volume of single trees based on measurements of tree diameter (or girth) alone or both diameter and height. Similarly, stand volumes can be estimated from point estimates of basal area and predominant height – both of which can be readily measured with simple inventory tools (e.g. an optical wedge and clinometer). However, estimates of teak volume (of trees or stands) appear to be biased if diameter or basal area alone (i.e. without measuring tree heights) is used to predict the volume of teak in young plantations. Therefore, measurement of height is recommended where ever possible. The equations presented should prove to be valuable aids in the determining the economic value of silvicultural interventions such as thinning, and to estimate volumes of standing trees or of smallholder teak woodlots prior to sale or for inventory purposes.

7.1.3 Site Index Models

The regression of plot height (mean and predominant heights – Figure 7.12) resulted in estimated regression coefficients (β_0 and β_1) of 2.97 and -3.94 (R^2 = 0.68), and 3.19 and -3.66 (R^2 = 0.65) for mean height and predominant height respectively. This leads to the following equations to predict site index of teak in the smallholder woodlots of northern Laos:

Mean Height: $$SI_{15} = \exp\left[\ln(Height) - 3.94\left(\frac{1}{15} - \frac{1}{Age}\right)\right]$$, and

Predominant Height: $$SI_{15} = \exp\left[\ln(PHeight) - 3.66\left(\frac{1}{15} - \frac{1}{Age}\right)\right]$$

where, measured mean or predominant height ('Height') and the actual age ('Age') of the stand is inserted to estimate the site index at the base age of 15 years ('SI_{15}') for either the mean or predominant height respectively. These site index equations provide a means to compare sites in terms of their suitability for growing teak and to provide a measure of site quality. To further assist assessments of site quality, the regression coefficients were also used to generate a set of site index curves for mean height and predominant height (Figures 7.13 and 7.14), with two site index curves plotted either side of the average site indices of 15 and 19 for mean and predominant height respectively.

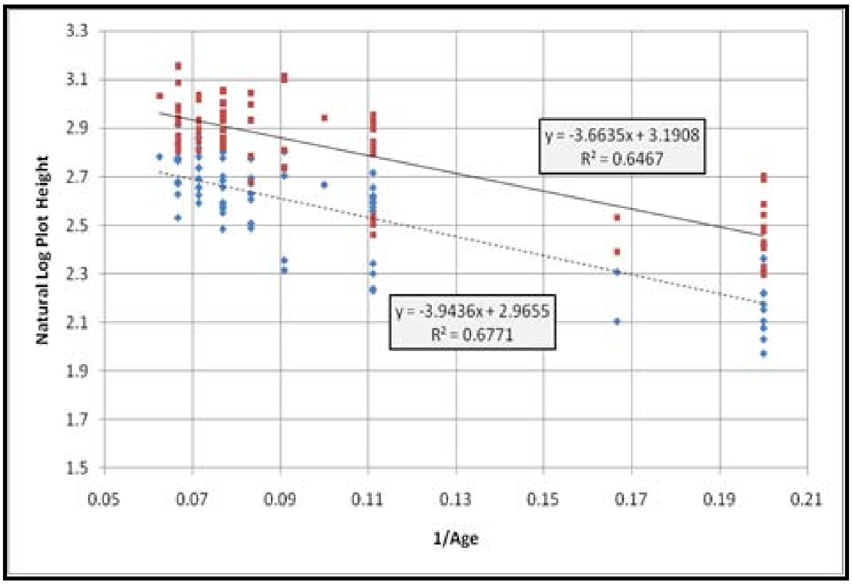

Figure 7.12: Relationship between natural log of plot height (m) of teak and the inverse of plot age (years). (Note: Red squares and blue diamonds are the observed values for plot predominant height and mean height respectively.)

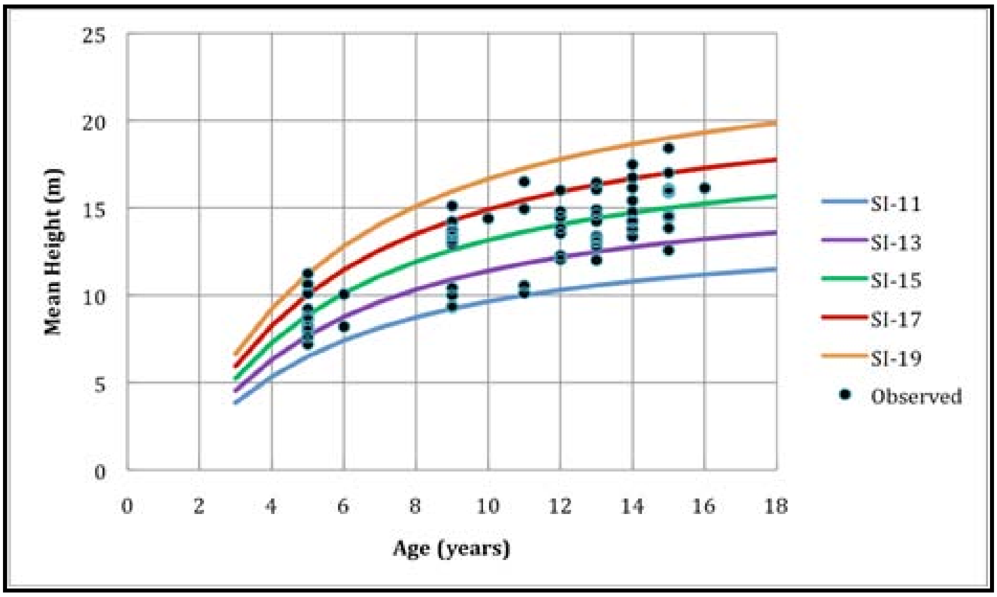

Figure 7.13: Site index (SI) curves for mean height of teak (base age = 15), for site indices from 11 to 19. (Note: average site index for mean height is 15, and the observed plot mean heights are plotted as closed circles.)

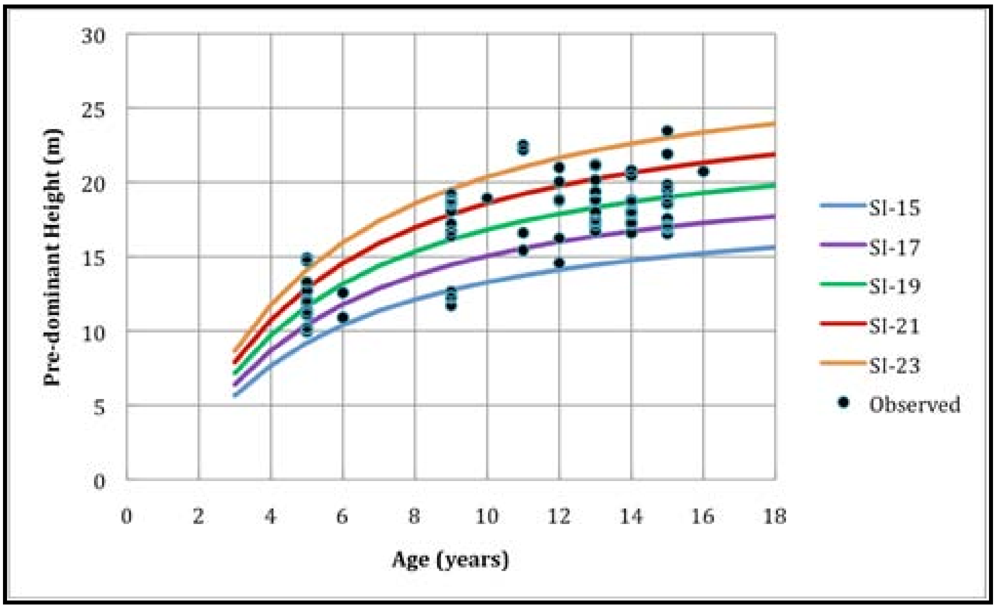

Figure 7.14: Site index (SI) curves for predominant height of teak (base age = 15), for site indices from 15 to 23. (Note: average SI for predominant height is 19, and observed predominant heights are plotted as closed circles.)

The site index equations developed and presented here indicate significant variation in the growth potential of different sites in Luang Prabang province for the growth of teak. Differences of 8m in mean height are projected between the lowest and highest site index classes at 15 years after planting. Site selection and/or fertilization therefore has the potential to greatly improve productivity of teak in smallholder woodlots. Further, this suggests that recommendations for silvicultural management of teak in this region need to take account of stand development and not just stand age.

7.1.4 Modelling Diameter

The site index models allow mean height or predominant height to be projected based on the stand age and stand height measured at that age. However, to build projections of volume on a site we also need to be able to model mean diameter at a given stocking (i.e. basal area per hectare) for specific site index and age. Therefore, the initial measurement data from all the permanent inventory plots (established to monitor impacts of thinning) was also used to model the response of diameter to stocking and age. Data indicated a strong relationship between mean height and diameter of teak, and also a relationship between age and both diameter and height (Figure 7.15). Therefore, regression analysis was used to develop a model to predict the mean diameter of teak trees in this region, based on measurements of age, mean stand height and stocking.

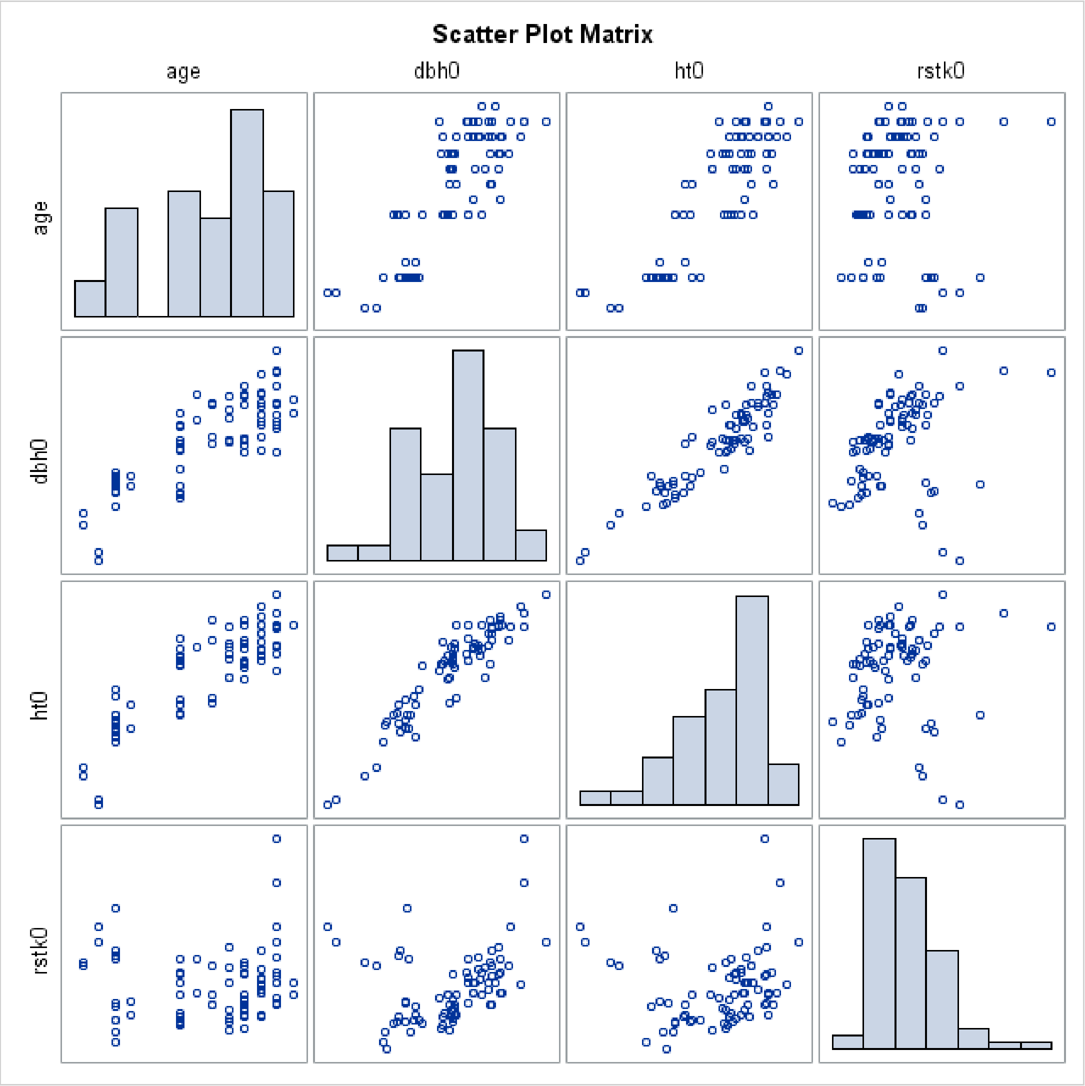

Figure 7.15: Frequency distributions on diagonal of plot age, mean diameter (dbh0), mean height (ht0) and the inverse of stocking (rstk0) as measured when the permanent plots were established in 2009 and 2010 (i.e. at time = 0, in relation to the thinning treatment). Off-diagonals are the scatter plots pairs of traits.

The best fitting regression model (R^2 = 0.91) with all terms significant to predict the mean diameter (dbh) of teak in Luang Prabang was:

$$DBH = -1.429 + 0.08527 Age + 0.7847 Ht + 2663\left(\frac{1}{Stk}\right)$$

where, DBH = is mean diameter at breast height (cm), Age = stand age in years, Ht = mean stand height (m) and Stk = stocking in stems per hectare.

This model was validated against independent data obtained from the Nelder wheel at the Northern Agriculture and Forestry College, using data collected at 4.4 years after planting. This demonstrated good correspondence between the actual diameter and predicted mean diameter at stockings between 600-2400 sph, but overestimated mean diameter at lower stocking levels (Table 7.2). Nevertheless the diameter model is reasonable within the range of stockings that are represented in the data (refer Table 7.3) that were used to develop the model.

Table 7.2: Measured diameter and height and predicted mean diameter using data at 4.4 years across all stocking levels in the Nelder Wheel at the Northern Agriculture and Forestry College.

Stocking	Measured Mean Diameter (cm)	Measured Mean Height (m)	Predicted Diameter (cm)
106	9.5	8.0	30.3
159	10.5	8.6	22.4
255	10.8	8.6	16.2
423	11.1	9.8	12.9
636	10.9	9.8	10.8
1026	10.3	10.6	9.8
1659	9.4	10.9	9.1
2424	8.6	10.8	8.5

7.1.5 Status of Smallholder Woodlots in Luang Prabang

Plot-level statistics collected when the plots were established, and prior to imposition of the thinning treatments, indicate that teak trees in the measured smallholder woodlots are growing on average 1 cm in diameter and 1 m in height each year, with mean annual volume increments of 10 m^3 ha^{-1} yr^{-1} (Table 7.3). The average basal area maximized between 11 and 13 years of age at around 21 m^2 ha^{-1}, but is possibly linked to the observed drop in mean stocking between the two oldest age classes (Table 7.3).

The site index predictions were reasonably consistent in terms of average, minimum and maximum values (Table 7.3), indicating that sites sampled have similar growth potential across the four age classes. The average site index (SI) of smallholder woodlots was approximately 19 across all age groups; nevertheless, there was substantial variation in the estimated SI ranging from approximately 14 to 24. This indicates significant variation is the quality of sites that are being used by smallholders to grow teak in Luang Prabang province, and that sites are not equally suited to profitable teak growing. This suggests the need to guidelines to assist smallholders make better informed decisions on the suitability of their land for conversion to teak woodlots.

Stocking levels observed are strongly skewed (Figure 7.16) with over 90% of the smallholder woodlots having stockings higher than the establishment rate of 1100 sph (i.e. 3 x 3) recommended by NAFReC and Government of Lao through the Luang Prabang Provincial Agriculture and Forestry Office (PAFO). Stocking rates across age classes indicate similar averages in stands up to 13 years of age (i.e. 1600-1700 sph on average, Table 7.3) suggesting that smallholders have not changed establishment practices over the last 12 years, to align with the wider initial spacing of 3 x 3 m that is currently recommended. The drop in stocking levels in the oldest age class measured (i.e. 14-16 years), is possibly attributable to thinning and/or mortality. However, as we avoided stands that with a history of thinning, this decline in stocking is therefore most likely due to the death of suppressed trees in these older stands. There was however no strong relationship between stocking and the standing basal area or standing volume in the teak woodlot measured (Figure 7.17). This indicates that productivity is not driven by solely by stocking.

Table 7.3: Summary of plot-level statistics by age class prior to imposition of thinning treatments.

		Age Class			
Trait Measured	**Statistic**	**5-7 yrs**	**8-10 yrs**	**11-13 yrs**	**14-16 yrs**
Number of plots measured		14	13 (14)†	23	24 (25)†
Mean Diameter (cm)	Average	8.3	10.7	12.5	13.9
	Standard Error‡	0.23	0.71	0.33	0.38
	Minimum	6.3	7.0	10.5	10.4
	Maximum	9.7	14.9	15.5	18.3
Mean Height (m)	Average	9.1	12.5	13.7	15.4
	Standard Error	0.33	0.56	0.36	0.28
	Minimum	7.2	9.3	10.1	12.6
	Maximum	11.2	15.1	16.5	18.4
Basal Area (m^2 ha^{-1})	Average	9.2	15.7	21.1	20.9
	Standard Error	0.92	1.25	0.68	0.96
	Minimum	4.3	9.0	15.6	12.8

	Maximum	14.7	22.4	30.1	29.8
Standing Volume (m^3 ha^{-1})	Average	38.0	91.3	132.2	142.3
	Standard Error	4.75	10.04	7.13	8.24
	Minimum	16.8	38.8	77.0	89.0
	Maximum	71.6	136.4	234.4	225.8
Mean Annual Increment	Average	7.4	10.0	10.8	9.8
(m^3 ha^{-1} yr^{-1})	Standard Error	0.95	1.09	0.64	0.58
	Minimum	3.4	4.3	6.8	5.9
	Maximum	14.3	15.2	21.3	16.1
Stocking (stems ha^{-1})	Average	1630	1695	1624	1316
	Standard Error	177	128	87	70
	Minimum	772	1080	988	556
	Maximum	3086	2284	2451	1975
Predicted Site Index for	Average	19.1	19.1	19.7	18.8
Predominant Height	Standard Error	0.72	0.94	0.48	0.35
at 15 years (m)	Minimum	15.7	13.8	15.5	16.5
	Maximum	24.3	22.6	24.6	23.5

† No accurate height data were recorded in two plots in the initial measurement due to a problem with the measurement equipment.

‡ Standard error of the average

Observed mean annual increments (i.e. standing volume divided by stand age) were primarily between 8 and 14 m^3/ha/yr (Figure 7.18) and averaged approximately 10m^3/ha/yr (Table 7.3) in stands over 8 years of age. This is also reflected in the regression of standing volume on age, and the regression of standing volume on age (Figure 7.19) indicating a slope 10.7m^3/ha/yr, but no significant relationship between MAI and age (Figure 7.19). Note, however that this does not indicate current annual increments of 10m^3/ha, but only represents snapshot of smallholder woodlots at the time these plots were first measured in 2009 or 2010. Current annual increments will be explored in more detail in the next section of this report.

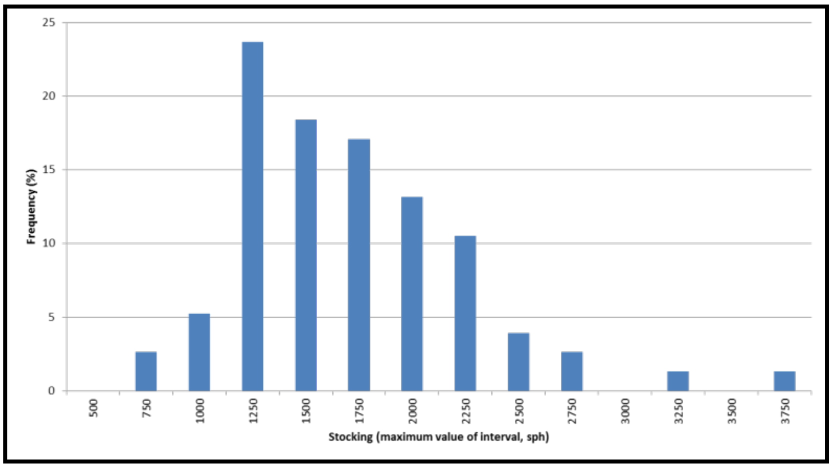

Figure 7.16: Distribution of stocking measured in smallholder teak woodlots in Luang Prabang.

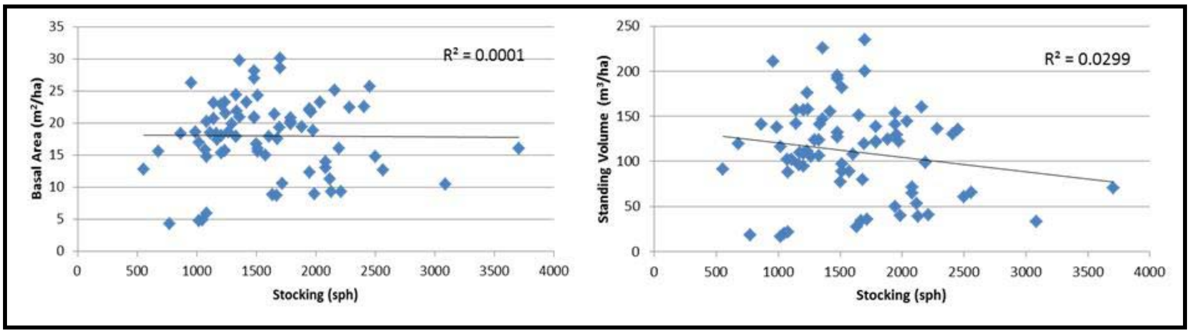

Figure 7.17: Relationship between stocking and both standing basal area (m^2/ha; left) and standing volume (m^3/ha; right) in teak woodlots of Luang Prabang.

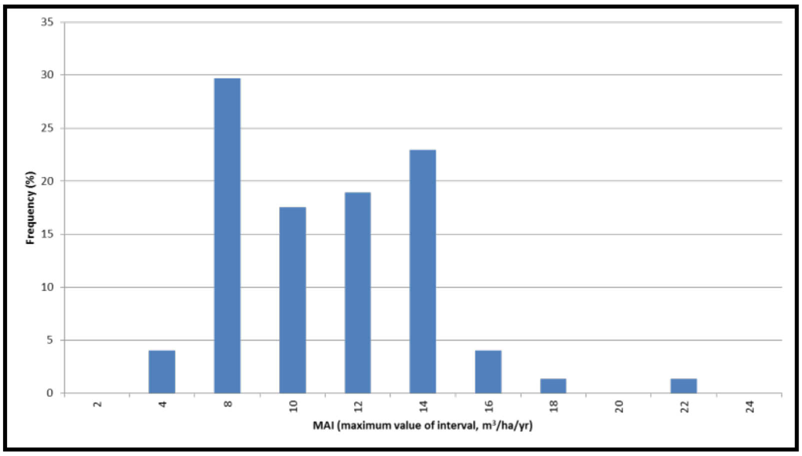

Figure 7.18: Distribution of mean annual increment (m^3/ha/yr) observed in smallholder teak woodlots of Luang Prabang.

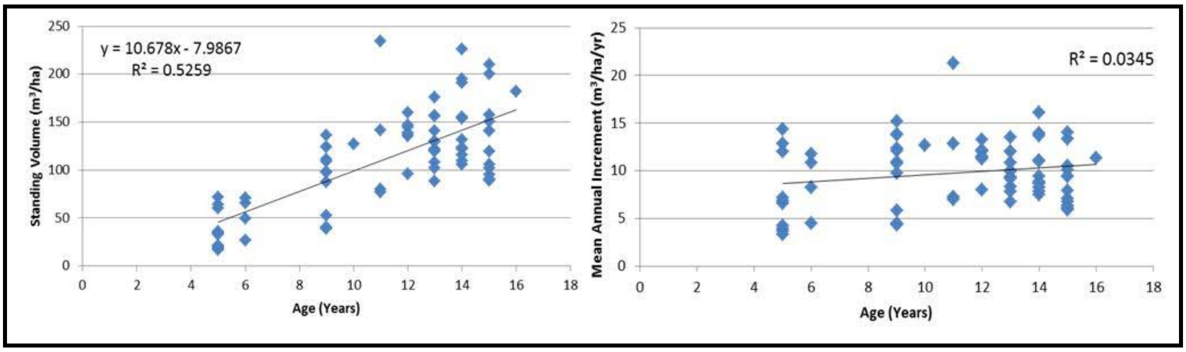

Figure 7.19: Relationship between both the standing volume (m^3/ha) and mean annual increment in volume (m^3/ha/year) for teak woodlots in Luang Prabang.

7.1.6 Response to Thinning

The thinning trials reported here do not form a neatly ordered set of treatments imposed on a uniform plantation of trees, of specified age. Rather, we have sought to investigate impacts of non-commercial thinning across the range of sites and stocking levels representative of smallholder teak plantations in Luang Prabang province. Complications and confounding effects include: differences the initial and residual stockings; variation in stocking levels between treated and control plots within a site, with the control plots tending to have higher initial stockings than the plots selected for thinning; differences in age at which the treatment was imposed; and inherent differences in site quality (as reflected in site index curves reported previously). The dispersed nature of smallholder teak woodlots required this experiment to be dispersed across sites and regions, and makes interpretation of results difficult. Yet, this study directly measures impacts of thinning within smallholder woodlots, and as such is directly relevant to these teak growers in Luang Prabang province. Further, establishment of thinning trials in this manner provides a tangible demonstration of appropriate silvicultural practices for farmers.

In an attempt to remove effects of age, sites were grouped into one of three age classes based on the age of the woodlot at the time the thinning treatment was imposed: A = 5-9 years, B = 10-12 years and C = 13-16 years. Changes were then averaged across the thinned and control plots (for sites with pair-plots) within each age class for the first, second, third and fourth year after thinning. As plots were established in 2009 and 2010, this meant that depending on the year of establishment, increments measured in the first year will have occurred in either the 2009 or 2010 wet season. Further, in the final year of the project 2012/13, only a subset of trial sites were remeasured; consequently, the set of trials representing increments in the third and fourth years are slightly different to those in the first and second years after thinning.

At the commencement of the study, when averaged across plots within age classes, the plots allocated for treatment and control plots had very similar average girth and tree height (Tables 7.4 and 7.5 – averages ‘at start’). Thinning treatments focused on preferentially removing the smallest trees in each plot, and then retaining trees of the best form. This can be seen to result in an increase in the mean girth and height following thinning (Tables 7.4 and 7.5 – averages ‘after thinning’), leading to increases in mean girth of approximately 5cm and average height of 1 to 1.5m as a direct consequence of removing the smallest trees in the thinned plots. There is also a slight change in the control plots following thinning – this reflects accidental removal of trees in some control plots. Differences in average size of the trees are maintained in the years following thinning, with no indication of further divergence in the average girth or height of the retained trees in the thinned plots, as would be expected if the trees in the thinned plots had larger increments than trees in the control plots. Nevertheless, if we look at the average girth increments, in the youngest stands (5-9 years) annual increments in girth are consistently higher in the thinned plots (Table 7.6); however, no such trend is evident in the older B and C age groups.

If the volume increments of the thinned and control plots are examined, there is a clear decline in total volume increment per hectare in the thinned plots (Table 7.7); reflecting the impacts of the reduced stocking on the total volume increment per hectare. Note however, these figures do not take into account the volume of wood that was removed in thinning, only the measured changes in the standing volume in one growing season from one measure to the next. These reductions in volume increment resulting from thinning become smaller with increasing age of the stands (Table 7.7); most probably reflecting the reduced contribution of the smallest trees in the stands to annual increments with increasing stand age.

In considering all the data from the farm-based thinning trials, the overall results suggest that precommercial thinning of these woodlots had little or not measurable impact when averaged across all stands within an age class. However, results vary considerably from stand to stand and the average results obscure some potentially important research findings.

Some stands demonstrate an improvement in basal area increment (m^2/ha/year), while others show little or not response when averaged across all trees on a plot. Further, some farmers removed additional trees from the trial plots during the course of the study – removal of a few large trees led to significant reduction in standing volumes and negative increments. Unfortunately, the inherent variablity between and within sites in this study perhaps meant that any differences in growth rates caused by thinning are obscured by the other sources of variation that could not be controlled in this study. Nevertheless, it is still important to remember that average size of trees was improved by thinning and so the volume increment that occurs following thinning is therefore acrewing on fewer trees, of larger average size and consequently higher value. Even if the total increment in volume is largely unchanged by thinning, the distribution of this increment is changed. Further studies should logically look at changes to stand value as a consequence of thinning.

Table 7.4: Average girth (cm) of trees in control and thinned plots, by age class (A, B and C), at commencement of experiment, once trees were removed in thinning, and then one, two, three or four years after thinning.

Mean Girth (cm)

	A: 5-9 yrs		B: 10-12 yrs		C: 13-16yrs	
	Control	Thin	Control	Thin	Control	Thin
Start	28.6	27.8	39.2	40.1	42.4	42.1
After thinning	28.9	32.0	39.8	46.0	42.8	47.1
+1yr	31.1	35.4	39.9	46.9	43.4	48.7
+2yrs	33.2	37.6	41.3	48.6	44.1	49.7
+3yrs	36.5	41.4	43.5	52.7	46.2	52.5
+4yrs	39.5	43.8	43.1	47.1	45.6	49.8

Table 7.5: Average height (m) of trees in control and thinned plots, by age class (A, B and C), at commencement of experiment, once trees were removed in thinning, and then one, two, three or four years after thinning.

Mean Height (m)

	A: 5-9 yrs		B: 10-12 yrs		C: 13-16yrs	
	Control	Thin	Control	Thin	Control	Thin
Start	10.7	10.5	13.5	13.2	15.1	14.7
After thinning	10.9	11.6	13.7	14.7	15.2	15.9
+1yr	12.1	13.0	14.9	16.5	16.0	17.4
+2yrs	13.2	14.3	15.9	17.7	16.8	18.0
+3yrs	13.9	15.2	17.3	19.8	18.2	19.3
+4yrs	14.0	14.7	16.2	19.3	18.1	20.6

Table 7.6: Average annual girth increment (cm/yr) of trees in control and thinned plots, by age class (A, B and C), and one, two, three or four years after thinning.

Girth Increment (cm/yr)

	A: 5-9 yrs		B: 10-12 yrs		C: 13-16yrs	
	Control	Thin	Control	Thin	Control	Thin
+1yr	1.43	2.39	0.13	0.89	0.16	0.78
+2yrs	2.15	2.26	1.44	1.70	1.14	1.07
+3yrs	2.73	3.30	2.53	1.04	2.39	2.17
+4yrs	1.65	1.90	1.88	0.80	0.52	-1.03

Table 7.7: Average annual volume increment (m^3/ha/yr) of trees in control and thinned plots, by age class (A, B and C), and one, two, three or four years after thinning.

Mean Annual Increment – Volume (m^3/ha/yr)

	A: 5-9 yrs		B: 10-12 yrs		C: 13-16yrs	
	Control	Thin	Control	Thin	Control	Thin
Start	9.7	8.7	12.4	11.1	10.0	9.5
+1yr	10.0	8.7	12.7	11.8	10.2	9.7
+2yrs	10.6	9.5	12.9	12.2	10.3	9.9
+3yrs	10.8	9.9	14.7	13.2	11.0	10.9
+4yrs	11.0	9.5	12.6	12.3	11.6	12.2

Observations during remeasurement of the plots suggested that growth increments were primarily occuring on the largest trees in each stand. Therefore, in an attempt to further clarify what might be occuring following thinning, we examined increments in trees of different girth classes. Here trees were assigned to a girth class (10 cm intervals, reflecting log valuation practices in Luang Prabang[5]) based on the size of the tree when it was first measured – with girth classes indicated by their midpoint, i.e. 5 = 0–10cm, 15 = 10–20cm, 25 = 20-30cm etc..

The number of age classes was progresively reduced, in attempt to simply results as much as possible and to group plots displaying similar response patterns after thinning. The two age classes used were: A = 5-9 years, and B = 10-16 years of age at the time of thinning. As changes in girth (π x diameter) most strongly reflect changes in tree value, results are presented for girth increments in the first, second and third years following thinning (Figures 7.20 to 7.22). Note that as only a subset of the sties were measured in 2012/13, results are presented only for the first three years following thinning.

Examination of Figures 7.20 to 7.22 demonstrate large differences in the current annual increments between the younger and older stands. In the older trial sties, girth increments of most trees are well below 2 cm per year, with many of the smaller trees below 1 cm per year. By contrast, in the younger stands the girth classes which comprise the vast majority of trees in these stands (i.e. 25 and 35 cm) had increments approaching or exceeding 2 cm per year. This means that most trees in the older stands will require 2 – 4 times longer to move from one (10 cm) girth class to the next, compared to trees in the younger stands. This also demonstrates that the current annual increments in the older stands are considerably lower than the mean annual increments noted in the previous section (Section 7.1.5).

The response to thinning also differs between the younger and older stands. In the first year following thinning (Figure 7.20) trees in the control plots are growing more slowly that the thinned plots in trials less than 10 years of age when thinned; however, in the older trials there is no difference in girth increment between the control and thinned plots, except for the largest trees in these stands. Examination of Figures 7.21 and 7.22 indicate similar patterns of response, except that the thinned plots in the younger stands show no advantage to the control plots in the second year; nevertheless, the greater girth increment across the size classes is once again evident in the third year after thinning (Figure 7.22). Why, however, are these patterns also not evident when examining the average changes in girth of all trees in the control and thinned plots? The most probable explanation is the differences in frequency of trees in each of the girth classes in thinned and control plots.

[5] *For example one sawmill operator in Xieng Ngeun in an interview on the 7th of December 2012, indicated that he was willing to pay 70,000, 80,000, 150,000 and 250,000 kip/tree for teak trees with a minimum girth of 70, 80, 90 and 100 cm respectively. Similar prices were also reported in discussions with farmers. However, the actual price paid to farmers is also dependent on distance from the road, tree age and log quality.*

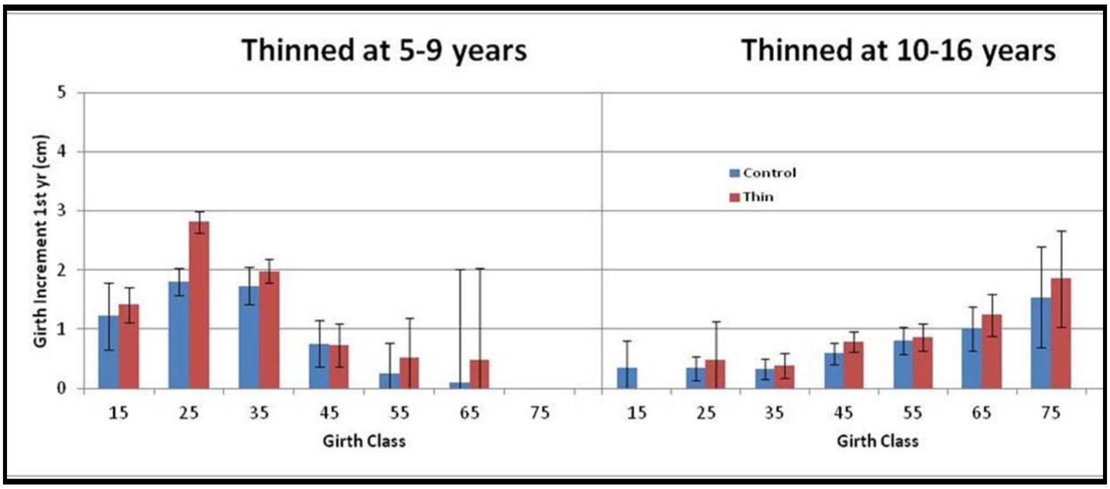

Figure 7.20: First year after thinning – Girth increment (cm) in thinned and control plots, averaged across plots aged 5-9 years and 10-16 years at the time of thinning. (Control – blue; Thinned – red)

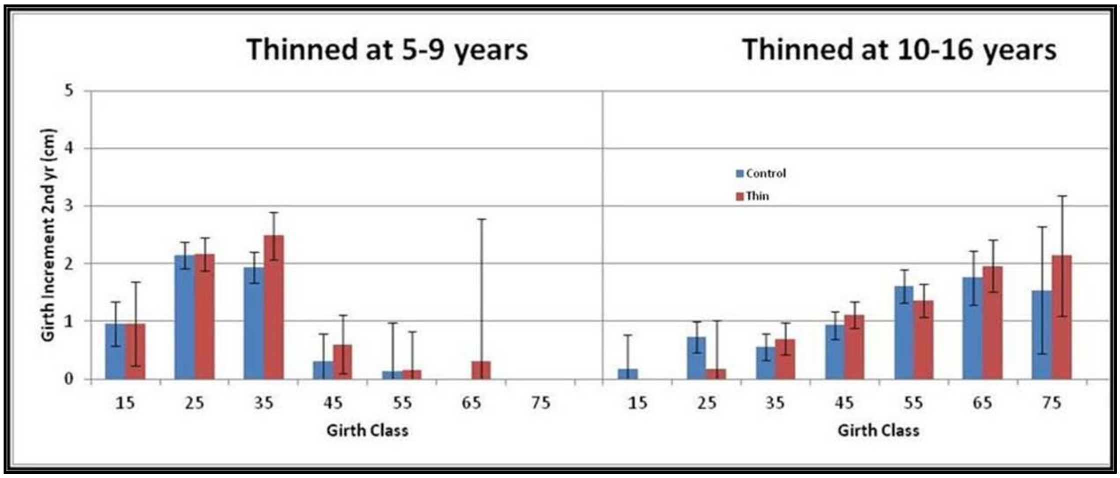

Figure 7.21: Second year after thinning – Girth increment (cm) in thinned and control plots, averaged across plots aged 5-9 years and 10-16 years at the time of thinning. (Control – blue; Thinned – red)

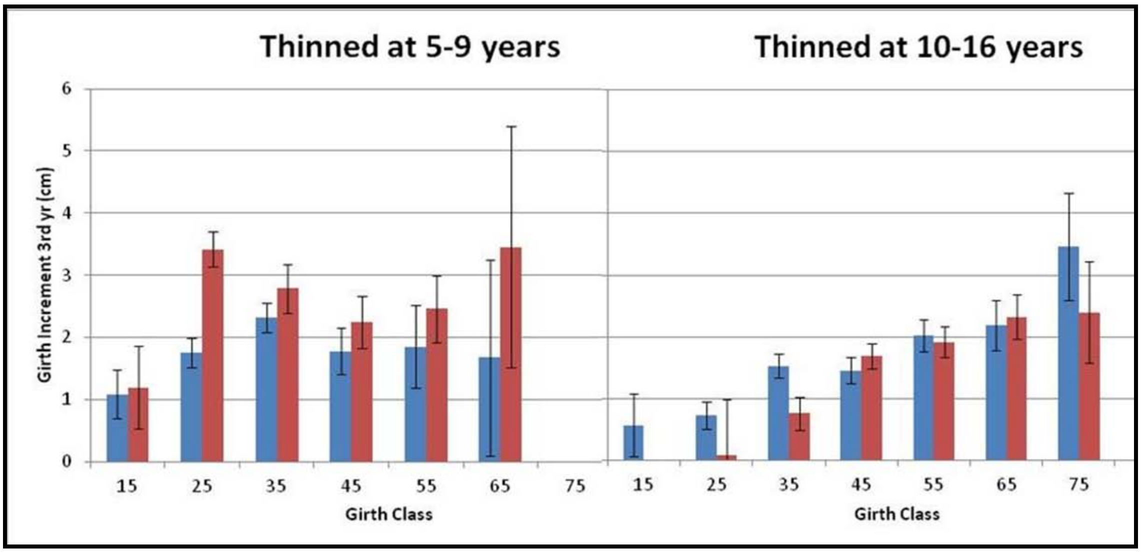

Figure 7.22: Third year after thinning – Girth increment (cm) in thinned and control plots, averaged across plots aged 5-9 years and 10-16 years at the time of thinning. (Control – blue; Thinned – red)

Overall the observed responses following thinning are complex. In general the average response is small. This possibly reflects the inherent variability in the trial sites as discussed above, but may also reflect that we were not able to impose a sufficiently heavy thinning to achieve a measurable response in terms of mean annual increments in girth or basal area. Thinning was imposed to target residual stocking, as conceptually this is simpler to explain than thinning to fixed basal area. Nevertheless, in hindsight it may have been more appropriate to thin to a constant basal area, thereby taking into account differences between sites relating to productivity and initial stocking rates.

When responses were examined by girth class to reflect differences in tree size at the time of thinning, it was clear that girth increments are not evenly distributed in the stands and response to thinning differed between the younger and older stands. When thinning was imposed on stands less than 10 years of age, there was generally an improved girth increment across all tree size classes. However, thinning of the older stands resulted in an improvement in the girth increment only in the largest (i.e. dominant) trees in the stands.

Further, there were clear differences in the girth increments observed between the younger and older stands – with relatively even growth pattern in the younger stands, while in the older stands the largest trees (dominant) had 2-4 times the growth increment of the smaller (suppressed, sub-dominant and co-dominant) trees. This indicates that the small trees in stands 10-16 years of age are growing very slowly and showing signs of high levels of suppression. Further, this suggests that the volume increments in the older stands are driven predominantly by the largest trees in these stands. These observed differences between stands up to 10 years of age and those 10-16 years of age, also strongly support the need for early thinning to maintain growth rates and stand health. Retention of small trees in the older stands will lead to little if any increment in value to these trees over the short term (3-5 year) as they are either suppressed or becoming suppressed with very small girth increments, and are likely to be lost through mortality in highly stock stands with increasing age.

To summarize:

- Thinning resulted in measurable and significant increase in average tree size as is expected when thinning is imposed from below.
- Overall response to thinning when measured in terms of current annual increment in volume or basal area per hectare, revealed little differences between the thinned and control plots. Nevertheless, the increment in the thinned plots is being accumulated on few, larger trees with greater value than in the control plots.
- When increments are viewed by tree size (girth class) and age class, clear differences were evident between the younger and older stands – younger stands indicate an improvement in girth increments across all size classes following thinning, however, the older stands only the largest trees demonstrated any response to thinning. Further, small trees in the older stands are growing very slowly, contributing to total standing volumes, but contributing little to volume increments.
- Results are complicated by the variable nature of the smallholder woodlots included in this study. However, it would appear that:
    - i) thinning needs to be more aggressive in order to achieve a large response – many of the thinned plots were not thinned to target residual stocking of 800 sph due to high initial stocking in some plots;
    - ii) thinning to constant basal area, although more difficult to explain to smallholders, will take into account differences in site productivity as well as differences in stocking as so is recommended in the future;
    - iii) response to thinning should attempt to focus on changes in stand value, rather than changes in volume, however the absence of any consistent log pricing makes this difficult;
    - iv) observed declines in girth increments with age, suggest a need to focus further research activities on non-commercial thinning of stands less than 10 years of age in order to maintain growth rates and stand health; and
    - v) retention of small trees in older stands contributes little (or nothing) to increments in value of these stands, as small trees are either suppressed or becoming suppressed and so grow very slowly compared to the larger, dominant trees in these stands, therefore farmers should be encouraged to adopt management practices that progressively remove the small trees in highly stocked, older stands as soon as possible.

7.2 Agroforestry Systems Research (Objective 2)

Teak was successfully established as part of the diverse agroforestry systems on ten sites in 2009 and 2010 surround the village of Ban Phonsavang, with the percentage of surviving trees typically exceeding 80% in the first two years after planting, but dropping to around 70% by the end of the third year (Figure 7.23). Growth of teak was extremely variable (Figure 7.24), reflecting both the companion crops, degree of maintenance provided by farmers in the first two years, as well as inherent differences in productivity between sites.

Four of the trials established in 2009 were measured for diameter at the end of the third and fourth growing season, mean data are presented in Figure 7.25 as girth and height increments in the fourth growing season. There are marked differences in the growth rates recorded for the teak trees in sites 1 and 2 compared to sites 5 and 6. Maintenance in site 2 was relatively poor, and trees experienced strong competition from paper mulberry and bananas. However, on site 6 the teak were planted between established banana plants, and similarly both sites 1 and 5 also included bananas as one of the companion crops, but there were only a small number of banana plants included on these sites. The most likely explanation is the relative position of the companion crops compared to the teak trees. In the case of site 6, the project team planted teak into the existing banana and were careful to position the teak in the centre of the existing rows of banana plants. On other sites, farmers established companion crops as they thought best, sometimes resulting in bananas, broom grass or paper mulberry being grown immediately adjacent to the teak trees. Nevertheless more comprehensive analyses of the differences between the sites are required.

In addition to measurement data collected on the developing teak crop, farmers were interviewed to determine the level of production from companion crops raised on these sites between 2009 and 2012 and the estimated value of these crops (Table 7.7). Total returns by year and commodity are summarised in Figure 7.26. Additional data has been collected from farmers based on time/labour inputs in the establishment and growing of these crops. A comprehensive analysis of inputs and returns and farmer attitudes will be conducted over the next 6 months, and these trials will be continued to be monitored. These results point to the ability of smallholders to successfully grow teak in combination with a range of crops. However, in order to maximise returns careful attention will be required to minimise competition between the various species.

The returns to the farmers from of the agroforestry plots are highly variable based on crop selection and management as well as variable prices for agricultural products. Not all collaborators started in the same year or continued to grow crops across the four years. However, the results show that income can be maintained into the fourth year with the mean gross cash income in the fourth year greater than 3 million kip per hectare ($375) for those farmers with four continuous years of production. However, the median gross income was only around 1.4 million kip. The main income source in the fourth years was from banana production. Activity budgeting showed that bananas produce a steady source of income that results in a net returns to household labour (NRHL) that tends to exceed the opportunity cost of labour[6]. However, the price of bananas varies from 1,000 to 2,000 kip per hand which has a large impact on the results. Transport and marketing costs are the main cash outlays, but also consume significant labour with one family member often away from the village overnight to sell their product at markets in Luang Prabang city.

In the early years, collaborators tended to plant Job's tears. While the production of the annual crop did produce cash income, budgeting activities carried out with several participants showed that the NRHL were quite low in 2011 (around 15,000 kip/man-day). This was largely a factor of poor yields and the amount of labour that is required for three weeding operations. In 2012, the yield for Job's tears improved, however the price fell substantially. In 2011 the price of the small seed variety of Job's was 5,000 kip/kg which fell to only 2,200 kip/kg in 2012. Despite this, the NRHL were still about 24,000 kip/man-day. According to a local trader in 2011 he sold Job's tears into Thailand and China and the fall in price was due to no sales into Thailand and reduced sales into China.

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[6] *Based on interviews, labour rates currently vary from 20,000 to 50,000 kip per person per day. With the highest rates reported in locations closer to Luang Prabang city, where there are more opportunities of off-farm labour.*

The NRHL from broom grass production was above the local wage rate with farmers collecting around 10 kg per person per day. Prices ranged from 3,000–5,000 kip/kg depending on the time in the collection season. On the other hand, paper mulberry was seen as a laborious activity that was no longer providing a return to labour that warranted its collection at current prices.

The results showed that annual cropping in the initial years of an agroforestry system can provide cash income; however, the returns to household labour are low and probably below the shadow wage rate particularly when the prices are unstable. However, labour used in the weeding of the annual crop includes the weeding and maintenance of the teak trees in the initial years. The establishment of bananas and planted NTFPs can provide good returns to labour at least up until year four and beyond. The wider spacing and better designed systems have greater potential to deliver higher incomes and for a longer period. However, more research and extension is required to develop and demonstrate various systems.

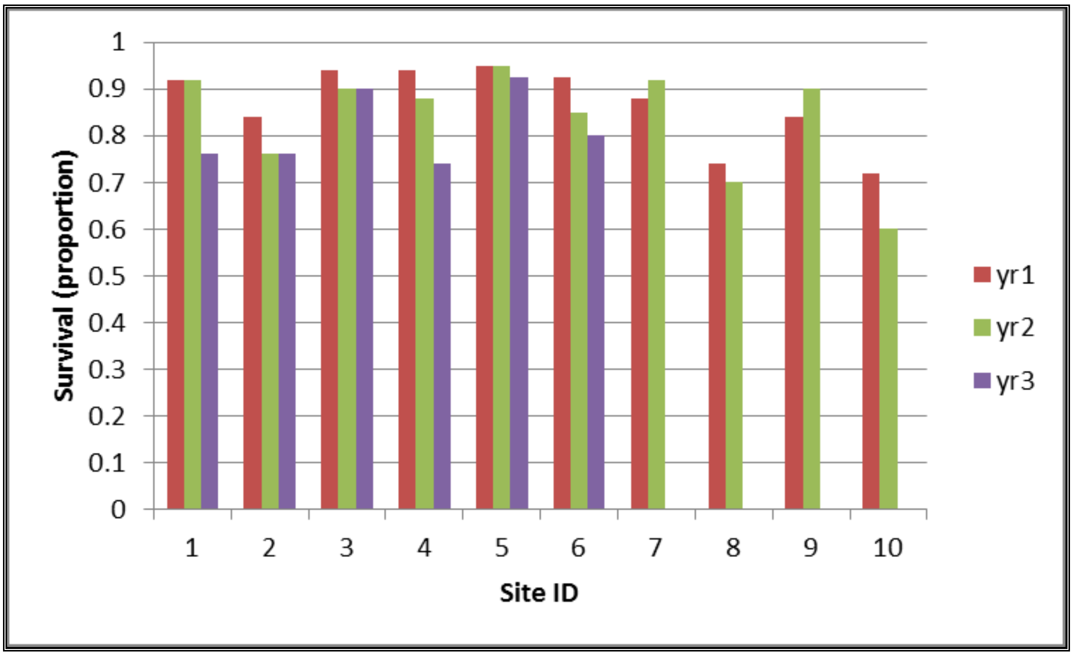

Figure 7.23: Mean proportion of planted teak trees surviving after the end of the first, second and third growing seasons.

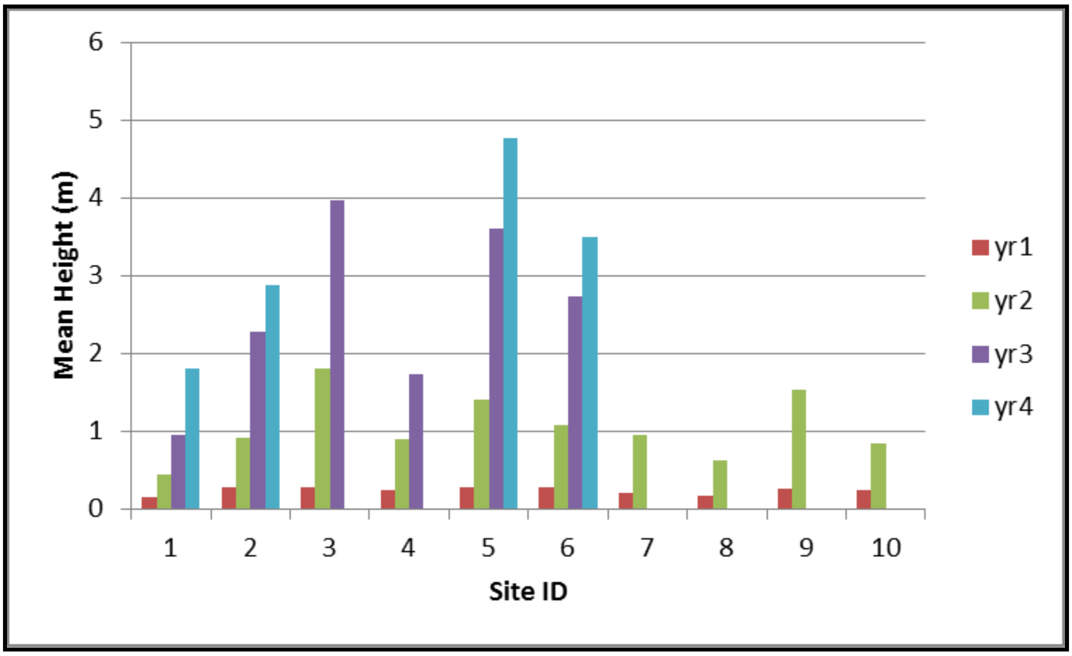

Figure 7.24: Mean height of teak trees in agroforestry trials at the end of each growing season from the first to the fourth year after planting.

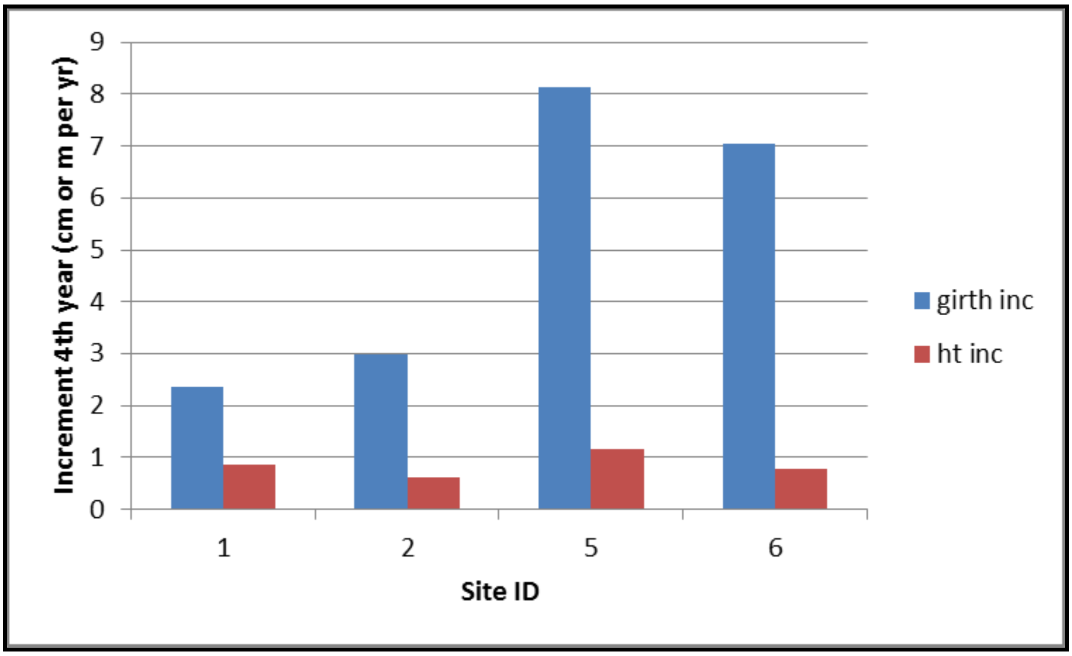

Figure 7.25: Mean girth and height increments in the fourth growing season in four of the first 6 agroforestry trials remeasured in 2012/13.

Table 7.7: Crops yields and returns (2009-2012) from agroforestry trials established in Ban Phonsavang in 2009 and 2010.

Nº	Name	Year	Crop species	Number of harvest	Units	Price (kip)	Gross Income (kip)
1	Mr Khamsone	2009	Job's tear(big grain)	900	kg	2500	2,250,000
1	Mr Khamsone	2009	Broom grass	200	kg	2500	500,000
1	Mr Khamsone	2009	Paper mulberry	250	kg	2000	500,000
2	Mr Khamphet	2009	Banana	1800	hands	1000	1,800,000
2	Mr Khamphet	2009	Broom grass	600	kg	2500	1,500,000
3	Mr Thong & Li	2009	Job's tear (small grain)	2000	kg	4000	8,000,000
3	Mr Thong & Li	2009	Paper mulberry	50	kg	2000	100,000
4	Mr Phondee	2009	Job's tear (big grain)	1200	kg	2500	3,000,000
5	Mr Sivane	2009	Banana	700	hands	1000	700,000
5	Mr Sivane	2009	Broom grass	640	kg	2500	1,600,000
5	Mr Sivane	2009	Paper mulberry	300	kg	2000	600,000
6	Mr Sivone	2009	Paper mulberry	100	kg	2000	200,000
1	Mr Khamsone	2010	Banana	2400	hands	1000	2,400,000
1	Mr Khamsone	2010	Broom grass	150	kg	2500	375,000
1	Mr Khamsone	2010	Paper mulberry	50	kg	3000	150,000
2	Mr Khamphet	2010	Banana	2000	hands	1000	2,000,000
2	Mr Khamphet	2010	Broom grass	480	kg	2500	1,200,000
3	Mr Thong & Li	2010	Job's tear (small grain)	1500	kg	4000	6,000,000
3	Mr Thong & Li	2010	Paper mulberry	70	kg	3000	210,000
3	Mr Thong & Li	2010	Banana	300	hands	1000	300,000
4	Mr Phondee	2010	Job's tear (big grain)	720	kg	2500	1,800,000
5	Mr Sivane	2010	Banana	1500	hands	1000	1,500,000
5	Mr Sivane	2010	Broom grass	720	kg	2500	1,800,000
5	Mr Sivane	2010	Paper Mulberry	140	kg	3000	420,000
6	Mr Sivone	2010	Banana	350	hands	1000	350,000
6	Mr Sivone	2010	Paper mulberry	80	kg	3000	240,000
1	Mr Khamsone	2011	Banana	3600	hands	1000	3,600,000
1	Mr Khamsone	2011	Broom grass	150	kg	5000	750,000
1	Mr Khamsone	2011	Paper mulberry	30	kg	3000	90,000
2	Mr Khamphet	2011	Banana	1500	hands	1,000	1,500,000
2	Mr Khamphet	2011	Broom grass	110	kg	5,000	550,000
3	Mr Thong & Li	2011	Banana	400	hands	1000	400,000
3	Mr Thong & Li	2011	Paper mulberry	150	kg	3000	450,000
5	Mr Sivane	2011	Banana	1700	hands	1000	1,700,000

Nº	Name	Year	Crop species	Number of harvest	Units	Price (kip)	Gross Income (kip)
5	Mr Sivane	2011	Broom grass	240	kg	5000	1,200,000
5	Mr Sivane	2011	Paper mulberry	170	kg	3000	510,000
7	Mr Phoun	2011	Banana	280	hands	1000	280,000
7	Mr Phoun	2011	Job's tear(big grain)	120	kg	2000	240,000
7	Mr Phoun	2011	Broom grass	40	kg	5000	200,000
8	Mr Cheab	2011	Job's tear (small grain)	720	kg	5000	3,600,000
9	Mr Deeyai	2011	Job's tear (small grain)	500	kg	5000	2,500,000
9	Mr Deeyai	2011	Job's tear (big grain)	250	kg	2000	500,000
10	Mr Chanty	2011	Banana	600	hands	1000	600,000
10	Mr Chanty	2011	Job's tear (small grain)	375	kg	5000	1,875,000
1	Mr Khamsone	2012	Banana	3000	hands	1000	3,000,000
1	Mr Khamsone	2012	Broom grass	100	kg	5000	500,000
1	Mr Khamsone	2012	Paper mulberry	40	kg	3000	120,000
2	Mr Khamphet	2012	Banana	600	hands	1,000	600,000
2	Mr Khamphet	2012	Broom grass	100	kg	5,000	500,000
3	Mr Thong & Li	2012	Banana	600	hands	1000	600,000
5	Mr Sivane	2012	Banana	1500	hands	1000	1,500,000
5	Mr Sivane	2012	Broom grass	280	kg	5000	1,400,000
5	Mr Sivane	2012	Paper Mulberry	200	kg	3000	600,000
7	Mr Phoun	2012	Banana	400	hands	1000	400,000
7	Mr Phoun	2012	Broom grass	60	kg	5000	300,000
9	Mr Deeyai	2012	Job's tear (big grain)	2000	kg	2200	4,400,000
9	Mr Deeyai	2012	Banana	200	hands	1000	200,000
10	Mr Chanty	2012	Banana	1000	hands	1000	1,000,000

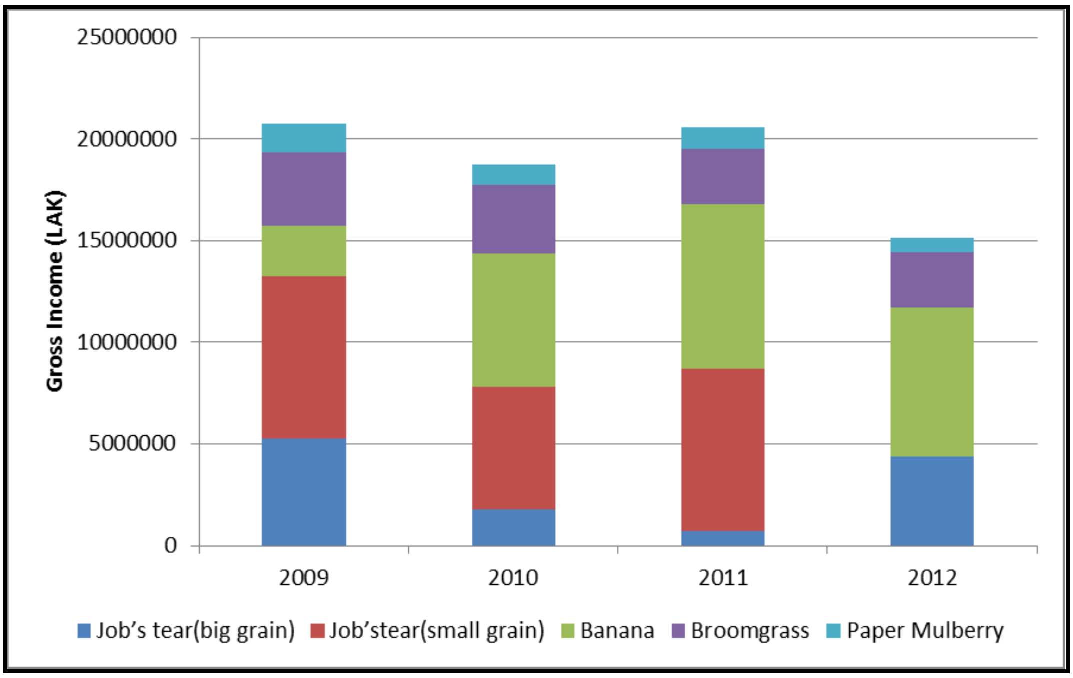

Figure 7.26: Total gross incomes from agroforestry trials by commodity.

7.3 Teak Genetic Improvement Research (Objective 3)

In 2010, fifty teak trees were selected from smallholder woodlots and other plantings around Luang Prabang, and green branches collected, and cut into 'sticks' to produce new shoots. The first few cuttings were set in May 2010. Attempts to propagate teak using this approached continued, with very limited success through until 2012. Poor rooting of shoots from sticks may have been partially caused by high pH of the spring water supply to the nursery; however after adoption of measures to correct the pH of the water supply (though treatment with HCl), there was not any noticeable improvement. Therefore in 2012 all remaining sticks were removed from the Houay Khot nursery, and the small number of rooted cuttings obtained were transferred to pots in the Houay Khot nursery.

Commencing in 2012 preliminary work commenced to investigate application of grafting for the propagation of teak, after Kikeo Singhalath joined the project team at NAFReC. This preliminary work indicated grafting success rates exceeding 70%. During 2012/13 a total of 100 elite trees were selected from diverse regions surround Luang Prabang, and propagated by grafting (Figure 7.27, Table 7.8). Some of these are the same trees selected in 2010 (e.g. trees selected in the DANIDA seed stand located near Ban Lak Sip – Site 7, Table 7.8), but as many of the trees selected in 2010 had been felled or could not be reliably identified in the field in 2012, most of these are new selections. Further, in 2012 we had a greater focus on assembling a diverse sample of selected trees, so more attention was given to selecting trees in different regions and different woodlots.

Grafted trees were established in a clone bank and seed orchard at the Agroforestry Research Station (Thong Khang) in 2013. Grafted trees have also been transferred to the Agriculture Research Center (Naphok, near Vientiane) as source of improved material to use in tissue culture experiments. It is anticipated that propagation using material from either the few successful cuttings or the established grafted trees/hedges will be much more successful than attempting direct propagation by cuttings from mature trees in the field.

Figure 7.27: Left: Somphanh Sakanphet beside an elite teak tree selected in Luang Prabang. (Photographer: Mark Dieters). Right: Successful teak graft (Photographer: Mark Dieters)

Table 7.8: Teak trees selected and grafted in 2013. Summary of grafting success by the location from which the trees were selected.

Site Nº	Location	Tree Code	Number of Grafts	Mortality (No.)	Survival (No.)	Survival (%)
1	Nam Ou	1-1	30	7	23	77
		1-2	30	15	15	50
		1-3	30	8	22	73
		1-4	30	1	29	97
		1-5	30	11	19	63
		1-6	30	10	20	67
		1-7	30	10	20	67
		1-8	30	15	15	50
		1-9	30	2	28	93
		1-10	30	3	27	90
		1-11	30	11	19	63
		1-12	30	8	22	73
		1-13	30	8	22	73
		1-14	30	11	19	63
		1-15	30	5	25	83
		Average		8	22	72
2	Namkhan-upper	2-1	30	7	23	77
		2-2	30	8	22	73
		2-3	30	6	24	80
		2-4	30	6	24	80
		2-5	30	10	20	67
		2-6	30	3	27	90
		2-7	30	5	25	83
		2-8	30	2	28	93
		2-9	30	6	24	80

Site Nº	Location	Tree Code	Number of Grafts	Mortality (No.)	Survival (No.)	Survival (%)
		2-10	30	2	28	93
		2-11	30	5	25	83
		2-12	30	10	20	67
		2-13	30	7	23	77
		2-14	30	12	18	60
		2-15	30	4	26	87
		Average		6	24	79
3	Namkhan-lower	3-1	30	4	26	87
		3-2	30	5	25	83
		3-3	30	7	23	77
		3-4	30	3	27	90
		3-5	30	10	20	67
		3-6	30	5	25	83
		3-7	30	5	25	83
		3-8	30	1	29	97
		3-9	30	1	29	97
		3-10	30	4	26	87
		3-11	30	3	27	90
		3-12	30	5	25	83
		3-13	30	9	21	70
		3-14	30	5	25	83
		3-15	30	8	22	73
		Average		5	25	83
4	Nam Sieang	4-1	30	15	15	50
		4-2	30	8	22	73
		4-3	30	9	21	70
		4-4	30	5	25	83
		4-5	30	12	18	60

Site Nº	Location	Tree Code	Number of Grafts	Mortality (No.)	Survival (No.)	Survival (%)
		4-6	30	12	18	60
		4-7	30	5	25	83
		4-8	30	4	26	87
		4-9	30	6	24	80
		4-10	30	3	27	90
		4-11	30	8	22	73
		4-12	30	8	22	73
		4-13	30	1	29	97
		4-14	30	2	28	93
		4-15	30	2	28	93
		Average		7	23	78
5	Namkong	5-1	30	3	27	90
		5-2	30	5	25	83
		5-3	30	4	26	87
		5-4	30	10	20	67
		5-5	30	3	27	90
		5-6	30	6	24	80
		5-7	30	9	21	70
		5-8	30	5	25	83
		5-9	30	11	19	63
		5-10	30	9	21	70
		5-11	30	7	23	77
		5-12	30	13	17	57
		5-13	30	4	26	87
		5-14	30	14	16	53
		5-15	30	10	20	67
		Average		8	22	75
6	Nan District	6-1	30	5	25	83

Site Nº	Location	Tree Code	Number of Grafts	Mortality (No.)	Survival (No.)	Survival (%)
		6-2	30	9	21	70
		6-3	30	5	25	83
		6-4	30	14	16	53
		6-5	30	5	25	83
		6-6	30	12	18	60
		6-7	30	12	18	60
		6-8	30	5	25	83
		6-9	30	7	23	77
		6-10	30	6	24	80
		6-11	30	13	17	57
		6-12	30	9	21	70
		6-13	30	15	15	50
		6-14	30	13	17	57
		6-15	30	15	15	50
		Average		10	20	68
7	DANIDA	7-1	30	10	20	67
		7-2	30	5	25	83
		7-3	30	5	25	83
		7-4	30	4	26	87
		7-5	30	9	21	70
		7-6	30	5	25	83
		7-7	30	4	26	87
		7-8	30	7	23	77
	B. Ean	1	30	1	29	97
		2	30	3	27	90
		Average		5	25	82

7.4 Socio-Economic Research (Objective 4)

7.4.1 Teak Planting and Agrarian differentiation

Smallholder teak plantations have had a long history in Luang Prabang province and are becoming increasingly important in the process of agrarian change and differentiation. Apart from the buoyant market for teak wood, expansion of teak smallholdings has been influenced by a range of policies that encourage timber production and discourage and restrict shifting cultivation. The land and forestry laws, supported by various government decrees, provide the institutional framework that gives farmers the security of tenure to invest in this long-term land-use option.

Households in the case study villages had diverse livelihoods, hence the ability to integrate teak into the farming system varied between villages and between households within villages. As such, the size of teak woodlots varied widely within and between case study villages. The overall mean woodlot size of the survey households was about 1,330 trees (1.4 ha) but varied from 750 trees in Ban Phatonglom to 2,110 trees in Ban Phonsavang. The distribution of woodlot size was positively skewed, so the mean woodlot size was inflated by a small number of larger woodlots (Fig. 7.28). About 20% of households surveyed had never planted teak, and 40% had planted less than 1,000 trees. The largest 10% of woodlots had holdings over 3,000 trees and ranged up to 20,000 trees.

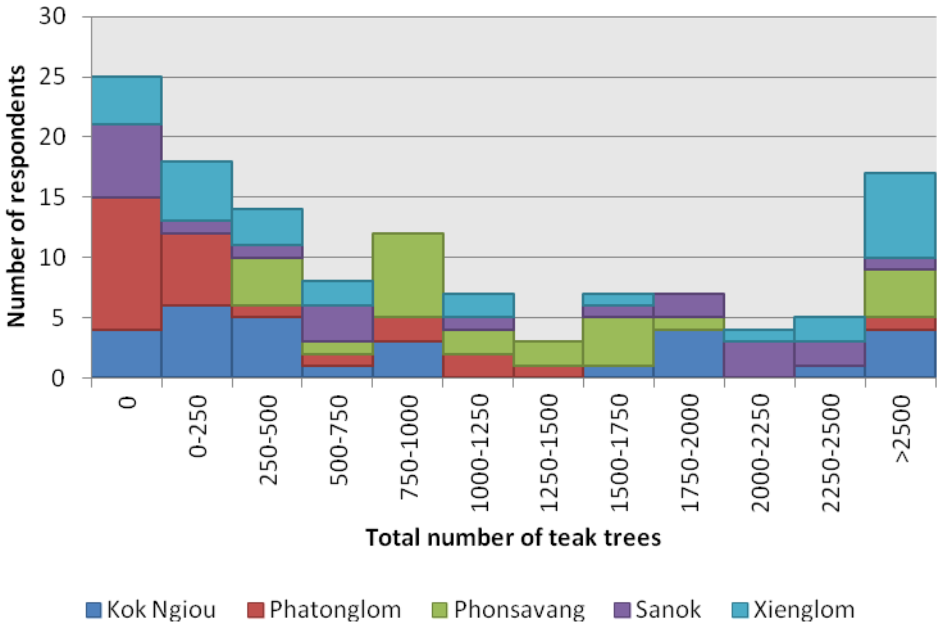

Figure 7.28: Distribution of woodlot size by village (number of trees).

It was hypothesized that the degree to which households were able to participate in teak planting and improved management was largely determined by the resources available to them, especially land and farm labour, and the alternative livelihood activities that their labour could be directed to, other than upland cropping (e.g. off-farm activities, paddy rice or vegetable gardens).

Households were classified into five groups (A-E) based on the number of teak trees they had planted, with Group A having no teak and Group E having 2,000 or more trees (Table 7.9). An exploratory analysis of factors influencing the adoption of teak was undertaken based on conventional statistical comparison of means and proportions between groups of respondents (reported in Newby *et al*. 2012).

Table 7.9: Survey households classified by number of teak trees and village.

Teak Group	Number of teak trees per household	Kok Ngiew	Phatong-lom	Phon-savang	Sanok	Xieng Lom	Total households
A	None	4	11	0	6	4	25
B	Less than 500	9	6	2	2	7	26
C	500–999	5	4	4	3	3	19
D	1,000–1999	5	3	14	3	3	28
E	Greater than 2,000	6	1	5	7	10	29
Total households		29	25	25	21	27	127

The average number of persons per household was 5.7. Households with teak tended to be smaller, better educated, with significantly ($p<0.01$) fewer dependants than non-teak households (Group A). This is to be expected given that, on average, the heads of teak-growing households were also older. The average number of off-farm workers per household was also positively correlated with the number of trees planted. Those households with alternative income sources had a greater ability to meet food requirements through purchases, and hence they were better able to convert cropland to tree plantations without reducing household food security.

Access to paddy land (also related to rice self-sufficiency) was seen as a major factor influencing the ability to adopt teak woodlots. While the Land Law allows for 1 ha of paddy per labour unit, the amount of paddy land available within the study villages was insufficient to provide each household with this amount. During the allocation process paddy land was often retained by those already using it, hence the distribution of land by area and productivity was not uniform. Respondents reported the area of their paddy land and the number and area of their cultivated upland parcels, fallowed parcels and timber (predominately teak) parcels (Table 7.10). Many respondents had difficulty distinguishing between currently cropped and fallowed land because these parcels regularly move in and out of cultivation. The process was further complicated by households not wanting to be seen to be violating the government policy on shifting cultivation.

The ratio of fallow to upland area was lower for those households with more teak because these households had used fallow land to plant teak (Table 7.10). This resulted in shorter rotations on the remaining upland parcels or a higher incidence of perennial crops, particularly pineapples and bananas. However, these households were also more likely to have access to paddy land, and so were more likely to be self-sufficient in rice; only 28%

of non-teak households were self-sufficient whereas over 50% of teak households were self-sufficient. While not having paddy land did not necessarily mean a household would not have teak, all those households that had paddy also had teak plantations, with the exception of households at Ban Phatonglom. Further, the average number of trees planted, and thus the area converted to teak, was significantly larger for households with paddy land.

Table 7.10: Access to land resources and cropping activities.

	Teak group†					
	A	B	C	D	E	Total
Parcels (mean number per household)						
No. upland parcels	1.7	1.9	2.1	1.7	1.6	1.8
No. parcels of fallow	1.9	1.3	0.9	0.7	0.8	1.1
No. parcels of timber land	0.2	0.9	1.5	1.8	2.8	1.5
Total parcels	3.8	4.1	4.5	4.2	5.1	4.4
Fallow/upland parcels	1.1	0.7	0.4	0.4	0.5	0.6
Land area (mean hectares per household)						
Area of paddy rice	0.3	0.3	0.3	0.4	0.6	0.4
Area of upland	1.4	1.5	1.4	1.2	1.0	1.3
Area of fallow	1.5	1.2	1.0	0.5	0.7	0.9
Area of timber land	0.2	0.4	0.7	1.2	2.1	1.0
Total area	3.3	3.4	3.5	3.3	4.5	3.6
Fallow/upland area	1.1	0.8	0.7	0.4	0.7	0.7
% timber land	5.4	12.5	21.3	37.6	47.0	27.3
Paddy rice						
% households with paddy	36.0	50.0	31.6	60.7	69.0	51.2
Area of paddy‡ (ha/hh)	0.7	0.7	1.0	0.6	0.8	0.38
Upland cropping (% of households)						
Any upland crop	88.0	84.6	84.2	64.3	62.1	75.6
Rice	59.1	36.4	25.0	16.7	33.3	35.4
Corn	45.5	22.7	18.8	33.3	33.3	31.3
Jobs tears	18.2	27.3	37.5	44.4	22.2	29.2
Sesame	18.2	9.1	12.5	11.1	33.3	16.7
Pineapple	13.6	36.4	31.3	16.7	22.2	24.0
Banana	4.5	18.2	43.8	44.4	38.9	28.1

† Refer to Table 7.9 for definition of teak groups.

‡Average area of paddy land for those household with paddy land.

The dominant upland crops in Table 7.10, with the exception of rice, were more a function of village location than the extent of teak planting. Pineapples were common in Ban Kok Ngiew, Job's tears (*Coix lacryma-jobi)* and bananas in Ban Phonsavang, corn in Ban Phatonglom and sesame in Ban Sanok. This pattern is thought to be related to previous development projects and/or the presence of traders who often promote and provide inputs for specific crops. In Ban Sanok the sesame was grown to be added to the river weed that was harvested and sold in Luang Prabang as a local delicacy.

Another important livelihood activity in Ban Xienglom and Ban Sanok was managing vegetable gardens, along the banks of the Khan and Mekong rivers respectively. These were often reported to be the main income-generating activity. The collection of non-timber forest products (NTFPs) was also an important activity for many households, especially in Ban Phonsavang. Products included broom grass, paper mulberry, bamboo, mushrooms, forest vegetables and rattan.

Those households without teak typically had fewer assets and lived in houses constructed of bamboo with a grass-thatch roof. This relative lack of assets was also related to some of the above factors, notably the age of the household head and the household's relocation history. Some of the variation in assets can also be explained by village-level factors, such as that electricity was not connected in Ban Sanok at the time of the survey, the lack of a mobile phone signal in Ban Phatonglom, and a fire in 2003 that destroyed the majority of houses in Ban Phatonglom. The causal relationships among the variables are complex. Did these households have more assets because they had planted and benefited from teak, or were they able to establish teak plantations because they had more resources to begin with? It would be too simplistic to conclude that households that had planted teak had benefited from the process, and therefore other households should follow the same 'pathway out of poverty'. While many households had benefited from the early adoption of teak, and commented that they had purchased motorbikes and two-wheel tractors and now sent their children to school with the income teak had generated, the ability of other households to follow this pathway depended on their initial resource endowment.

The asset levels of those households that had planted and not yet harvested teak tended to be higher than those of households that had never planted teak, which suggests that household accumulation of wealth is also an enabling factor rather than simply an impact of teak woodlots. Nevertheless, early planters who had already harvested some teak tended to have greater wealth than other teak households that had not yet harvested any trees.

During the interviews, households were asked if they had purchased or sold land in the past. Given the sensitive nature of the topic, they were not asked for details about to whom they sold land, although information regarding the number of trees was obtained. For those households that had purchased land, information regarding the land-use of the parcel was also obtained. Overall 36% of households had purchased land and 21% had sold land, with percentages relatively constant across the teak groups. The results suggest that households in the survey were purchasing both teak blocks and fallow land that they later converted to teak; however, fallow land should not be sold under the land law. Given that the survey did not include absentee landlords, the full extent of land transactions is difficult to quantify. Anecdotal evidence, however, suggests that the scale of land transactions is increasing, with investors looking for land on which to plant both teak and rubber. The money from land sales was reported to be used for school fees, weddings and to meet healthcare expenses.

Credit was available to farmers in some villages, including loans from the Agricultural Cooperation Bank, village revolving funds or from relatives. The bank interest rate ranged between 12 and 15% per year. Money could be borrowed from the village revolving fund for about 3% interest per month. The incidence of borrowing was higher among non-teak households and those with smaller plantations, suggesting that teak plantations (like rubber plantations) substitute for borrowed capital, providing a 'bank' to fund household needs as they arise.

In summary, teak planting has been more extensive among households with a longer history of settlement, where the household head was older and better educated, where household members had off-farm sources of income, and where the household had access to paddy land and so was thus more likely to be self- sufficient in rice. For these households, teak planting presents a land-use option that requires less labour input and, if managed effectively, can substantially improve household income. Indeed, it has already done so for the early adopters in this survey. While these households have more diversified livelihoods and were relatively better off compared to other members of the community, the majority of households included in the survey remain smallholder farming households with low returns to land and labour, and low incomes.

For households that depend on shifting cultivation for their livelihoods, the role that teak plays in their livelihood strategy has changed little since the 1950s. Many of these households reported that they borrowed land for upland rice production on the condition that after harvest they established teak for the owner. The next year they would have to find a new piece of land to grow their crops. However, because the area of teak has expanded, these households reported that they now have to travel further afield, often walking to neighbouring villages and into more remote and steeper country.

Hansen *et al.* (2005) advocated smaller plantations of 50–200 trees that farmers would be able to maintain with better management techniques and be less likely to sell early. The data presented in this report suggest that there are few households establishing such small numbers of trees. Therefore, without access to alternative productive land or income sources, maintaining ownership of teak land will continue to be difficult for many households.

Research by ACIAR and other agencies on teak agroforestry systems that provide short and medium-term cash flow (e.g., under-planting with rattan or intercropping with paper mulberry) may enable a more gradual transition to teak systems for households with little land. However, farmers with alternative livelihood activities and absentee landlords are unlikely to adopt these more diversified and labour-using systems. For these households, the establishment of teak woodlots not only represents a source of future income and wealth, but also provides a method for maintaining access to land beyond the area that they can physically cultivate. As such, developing recommendations and extension material for lower initial stocking (to maintain good growth rates and tree form) will be important for these households.

In conclusion, this research reveals that the establishment and improvement of teak woodlots, like other apparently technical interventions aimed at providing a 'pathway out of poverty', needs to be seen in the context of the wider processes of agrarian change and differentiation to appreciate the resultant impacts on livelihood trajectories. Extension materials on stocking, spacing and management need to capture the diversity of household situations and be targeted accordingly.

7.4.2 Management and Marketing of Teak

The rapid expansion of smallholder woodlots has not been followed by the adoption of recommended management practices. For the most recent wave of planting in the early 2000s, the optimal time for adopting pruning and thinning is imminent. Survey responses suggest landholders lack knowledge of management practices, especially thinning, hence improved extension should been seen as a high priority. However, farmers will need to be convinced that there are substantial economic returns to improved silvicultural practices before they will allocate scarce labour to practices with a long-term payoff, especially those with larger woodlots for whom teak planting is seen as a way of making land productive with reduced labour.

While about 40% of surveyed households had done some pruning, only 9% had done any thinning. The data also suggest that although individuals had attended training events on thinning, they were not confident they knew the appropriate method. Similarly, about a quarter of those farmers who reported that they had done some pruning were still not sure of the appropriate method.

The younger plantations were not yet at the stage when thinning and pruning is required. However, the limited knowledge among farmers highlights the importance of conducting extension activities on these techniques as the appropriate time for their adoption approaches. Surveys conducted with farmers prior to training workshops further highlighted that the majority of participants were unaware of any benefits of pruning their trees, and about half did not perceive any benefits from thinning their plantations.

Prior experience with marketing harvested teak was also limited among the households surveyed. About 68% of those households that had planted teak were yet to harvest any trees, and a further 18% had sold less than 50 trees, reflecting the age structure of the teak plantations. To date, the sale of trees has been dominated by those villages with the longer history of teak growing; in the survey, about two-thirds (67%) of reported harvested trees were from households in Ban Xienglom. In Ban Phonsavang, where the teak boom occurred more recently, only one of the households surveyed had begun to harvest and sell trees.

7.4.3 Forest and livelihood transition pathways

Within the study area several overlapping influences have induced the overall land-use change associated with the establishment of tree-based farming systems. However, there is a spectrum of farming and livelihood systems between the two extremes of absentee urban-based landowners who have acquired teak holdings and rural households that have recently relocated from more remote upland areas and remain highly dependent on swidden agriculture. These systems are managed by households with a variety of livelihood platforms, responding dynamically to different opportunities and constraints as they arise. These include variations in land types and productivity, population growth, access to land, access to markets, non-farm employment opportunities and *ad hoc* policy changes. The case studies revealed that land-use change occurring at the household scale is following different pathways, even for households in the same village occupying adjacent parcels of land. At the same time, these households are by no means on smooth, continuous “pathways”; the predominant trends are punctuated by unanticipated shocks that have significant and long-lasting impacts on households that are often living on the margin. Three of the forest transition pathways identified by Lambin and Meyfroidt (2010) were clearly distinguishable and relevant to current research and extension activities – an economic development pathway, a smallholder intensification pathway, and a state policy pathway. Table 7.11 summarises some of the characteristics of households on the three pathways described, outlines some priorities for research and extension, and identifies ongoing constraints. The external influence of government policies was felt by all households. Nevertheless, we only consider households as being on a state policy pathway when other factors inducing the transition are absent.

Table 7.11: Characteristics, opportunities, and constraints of households following different forest transition pathways.

	Economic development pathway	**Smallholder intensification pathway**	**State policy pathway**
Characteristics of household livelihood system	Access to paddy land and river gardens Labour shortage for upland agricultural activities Non-farm major income sources Strategic sales of land and trees to invest in productive activities Greater ability to allow trees to meet maturity	Limited access to paddy and gardens Land shortages to allow long fallow Some off- and non-farm employment, but labour concentrated on agricultural activities Strategic and some distress sales	No paddy and limited lowland activities Land constraints Non-farm and off-farm income necessary to meet subsistence needs Distressed sales of woodlots Declining upland yields
Tree-system of interest to households	Woodlots	Agroforestry	Small woodlots and boundary plantings Other alternatives to shifting cultivation
Research and extension	Spacing, thinning regimes Pruning Improved marketing	Spacing Companion cash crops NTFP Tree genetics Marketing of trees and crops	Farm planning - “Think before you plant”
Constraints	Limited labour to manage activities remains an issue Markets	Limited land Market uncertainty	Limited land Limited other agricultural activities Labour directed into non-farm to support consumption

The economic development pathway

The economic development pathway describes a situation where labour scarcity rather than forest scarcity is the major driver of land-use change. This labour scarcity is relative to the size of a household's landholdings and the extent of its engagement in other livelihood activities. Smallholder teak plantations have been identified by government planners as an alternative to swidden agriculture. While teak may provide an alternative use of land, the 2009 survey showed that households which already had alternatives to swidden were more likely to plant teak and to plant larger areas of teak. Paddy rice (Kok Ngiew, Xienglom, Phonsavang, Phatonglom), river-bank vegetable gardens (Xienglom and Sanok), and non-farm employment all provided households with alternative uses of labour to swidden agriculture and hence an incentive to plant teak woodlots in their upland fields. For these households, state policies designed to reduce swidden agriculture (such as limiting fallow periods) provided an additional incentive to convert their upland fields rather than risk having them reallocated to other households in the village.

Case studies in Kok Ngiew and Xienglom showed that households with alternative uses for their labour often allowed tenant farmers to cultivate their land during the initial years of teak establishment in return for managing the planted trees. This included land owned by absentee landowners. Indeed, land-scarce households from adjacent villages were using upland parcels for rice production from land-abundant households in Xienglom that had both paddy rice and vegetable activities. Returns from these activities have improved in recent years with improved road infrastructure, market access, and market demand with the expanding tourism sector. Electrification has also made irrigation with pumps and sprinklers more efficient, hence vegetable production is now a year-round activity for specialist producers.

In the short-term, this relationship has given tenants continued access to land while the landholders have been able to maintain ownership of their upland parcels and build up their area of teak woodlots, with limited labour required for maintenance following establishment. For households with less paddy land or limited access to river gardens, managing this land-use adjustment has been more complicated; for these households, income from upland crops and NTFPs collected from fallow fields was still important. Some case-study households had established teak on a large percentage of their upland parcels and now needed to enter the land market (leasing land from absentee landowners with in-kind labour payments) to bridge the period until their teak could be harvested. Livelihood shocks such as medical emergencies, low prices for cash crops and crop failure, posed a threat to the ability of these households to maintain ownership of the immature teak plantations. In these cases, livelihood diversification into off-farm and non-farm activities was driven by necessity rather than a planned reallocation of labour away from agriculture.

Even the case-study household in Kok Ngiew with the most land had strategically been borrowing cropping land in neighbouring Xienglom, allowing them to make a smoother transition. They are reaping the rewards from this investment, given that they are now less able to manage the strenuous work of upland cropping and their children are mostly employed in non-farm activities. Similarly, a young farmer in Sanok, who now also has limited upland cropping activities, inherited a large tree portfolio that was established when land was more abundant.

In the villages located closer to Luang Prabang city, non-farm activities were a major livelihood component. This included activities such as operating small shops, trading agricultural products, and employment in the large tourism sector. Rural wages increased significantly over the period of the study; farmers now earn around 30,000 kip/day (USD 3.75) for agricultural activities such as transplanting paddy rice, or over 50,000 kip/day (USD 6.30) for non-farm labouring. This increase has made the returns for many upland agricultural activities marginal at best when compared to the shadow value of household labour. The tourism sector continues to pull labour out of agricultural activities. Younger members of several case-study households were employed in eco-tourism, while an older case-study farmer in Sanok had recently sold two of his teak plantations (including the land) so that he could purchase a river-boat to take advantage of the increasing opportunities. These strategic sales of woodlots to invest in alternative livelihood opportunities are different to distress sales in response to livelihood shocks.

While the economic development pathway has seen widespread establishment of woodlots on former cropping land due to labour scarcity, this has also contributed to the poor on-going management of those stands. Once the trees are established and maintained for a few years, they are largely left to grow, with limited labour dedicated to their management. Demonstrating the economic benefits of improved management practices remains an important extension priority. A network of demonstration plots has been established to help in this effort.

Smallholder intensification pathway

The smallholder intensification pathway is similar to the economic development pathway in that it is often associated with a reallocation of labour between different land types, for example, concentration of labour on paddy rice plots in valley bottoms and river gardens, with tree plantations established on steep slopes that had previously been cultivated extensively (Meyfroidt and Lambin, 2008). However, where access to alternative land types is constrained, complex agroforestry systems have been developed on upland plots that feature a portfolio of activities providing a range of income streams over different time horizons.

In Kok Ngiew, the dominant upland cropping system that has emerged involves pineapples grown as a companion crop with teak, with households managing a staggered build-up of teak over several years in an attempt to maintain cash flow. The transition has been easier for those households with access to paddy land to provide a consumption buffer, particularly given large fluctuations in the pineapple price. Access to fallow and forest land also provides important income through the collection of NTFPs such as broom grass and bamboo shoots. In Phonsavang, agroforestry systems consisting of cash crops (Job's tears [*Coix lacryma-jobi*] and maize), domesticated NTFPs (paper mulberry [*Broussonetia papyrifera*] and broom grass [*Thysanchaena maxima*]), trees (teak and rubber [*Hevea brasilinesis*]), and perennials (bananas) have been developed. These systems continue to evolve in response to changing market conditions, with returns to family labour remaining an important criterion. Case-study farmers in Phonsavang have reduced the time dedicated to harvesting their paper mulberry due to falling prices, that have made the returns to labour too low compared to alternatives. At the same time, various bio-fuel crops such as *Jatropha curcas* and *Vernicia fordii* are being promoted and taken up by some farmers.

The current management of teak trees by these households is also mainly limited to weeding trees during the initial years when companion crops are becoming established. However, unlike many of the teak woodlots belonging to households on an economic development pathway, household workers are frequently in these fields, managing and harvesting other components of the system. For example, case-study farmers in Phonsavang spend some time during most weeks harvesting bananas from their agroforestry plots. While labour is more readily available, demonstrating the benefits of silvicultural practices such as thinning and pruning remains important as case-study households continue to see all trees as having some future value.

State policy pathway

Various government policies have acted both to encourage smallholder forestry and to restrict other forms of land use, especially swidden. A major influence on smallholder forestry has been the Government of Lao's Land and Forest Allocation (LFA) Policy (Newby et al. 2011; Fujita 2010). As outlined above, many farmers have planted teak on the upland parcels they do not currently need for food crops to retain this land for the future. The land allocation process also created an incentive for households to convert swidden land (that would be classified as "degraded forest land") into woodlots before the implementation of the allocation process in order to secure additional land. Planting teak has also converted the land into an asset that can be used as security for loans or sold to investors.

Case studies were conducted with several households whose farming systems were undergoing change primarily due to state policies. These included households that were not active teak growers due to inadequate resources to make the transition. In three villages (Kok Ngiew, Xienglom and Sanok), the case-study households in this category were not available for the second interview in 2012 as they were temporarily absent from the village or had relocated in order to find employment. These households had typically struggled to develop a sustainable upland cropping system, given declining fallow periods, soil fertility, and yields. In some cases land was left fallow to regenerate while household members moved into the non-farm sector.

8 Impacts

When determining the impacts of the project, the fundamental task is to trace the way in which the research has led to change. This process of tracing through the complex causal links between the research and the ultimate impacts (known as 'impact pathway analysis') is difficult from a forestry or agroforestry project with long lags between the research outputs and final impact compared to other farming systems. The resulting pathway is a description of how the project inputs produce a range of outputs that in turn deliver benefits, including through unexpected consequences. The outcomes are the changes in practices, products or policies that follow the adoption of an output by stakeholders. Aggregating these outcomes across the final users gives the initial impact—changes in market, environmental or social conditions.

As noted by Mercer (2004) "no matter how elegant, efficient, productive, and/or ecologically sustainable, agroforestry systems can contribute to sustainable land use only if they are adopted and maintained over long time periods". Adoption happens when individuals or firms have an incentive to adopt—the pay-off from the change more than compensates for the cost of making the change. While the adoption of new practices that improve the livelihoods of smallholder teak farmers is the ultimate goal of this project, given that adoption is a learning process there are a number of intermediate impacts that must occur first. Again, the nature of the project means that this learning process can be quite long as farmers evaluate the relative benefits of adopting new practices. However, a key objective of the project has been to create the infrastructure to better enable farmers to observe the benefits of improved management (known as the 'non-trial evaluation phase') which is difficult for individual smallholders to achieve on their own.

While the outputs of the project may not have led to widespread adoption at this stage, research and extension activities can be monitored and evaluated using Bennett's (1975) well-established hierarchy of variables. This framework recognises that there is a sequence of impacts attributable (at least in part) to an intervention, each of which can in principle be measured and monitored. Similar to the impact pathway, this sequence proceeds from the inputs used in a research and extension activity (e.g. staff days) to the activities implemented (e.g. farmer field visits) to the level of participation of the intended group (e.g. numbers attending) to the reaction or responses of the participants (e.g. as expressed in an end-of-workshop evaluation) to the knowledge, attitudes, skills, and aspirations acquired (KASA), to the actual change of practices in farming systems (e.g. as measured by follow-up adoption surveys), to the impact of these changed practices on social, economic and environmental outcomes (such as increased household income or reduced soil erosion). As we move through the hierarchy we are talking about longer-term impacts, well beyond the current phase of the project. In addition, it becomes increasingly difficult to attribute the impacts to the initial intervention, as many other factors and influences come to bear on the outcomes.

There are several pathways to adoption outlined in the literature, including: commercialisation, communication, capacity building, and regulation. This project has focused largely on capacity building and communication pathways; although through partnerships with government institutions there have been opportunities to influence both new regulations and the adjustment of regulations and policies that are having an unintended impact. Furthermore, a commercialisation pathway is planned for some of the genetic improvement research that has been initiated under this project and which will continue in the subsequent project.

Despite the achievements so far, it is recognised that the capacity built has to be utilised in the future before it will generate widespread outcomes at the community level and in turn produce final impacts. The potential impact pathways are illustrated in Figure 8.1. The project has been successful in establishing a range of partnerships and learning sites that can be utilised by government agencies (NAFREC, DAFO, PAFO), educational institutions (Souphanouvong University and the Northern Agriculture and Forestry College), and NGOs, for both ongoing research and extension. The research results and the development of learning sites (thinning demonstrations, Nelder wheels and agroforestry demonstration sites) have already led to changes in extension messages and the teaching curriculum of the partner institutions.

Project staff have conducted a series of training days with groups of farmers and held cross-site visits to thinning trials, agroforestry trials and the Nelder wheels. Monitoring and evaluation (M&E) has shown that this has already led to farmer-to-farmer learning. Interviews conducted with village officials have shown that, while they may not be directly involved in the project (through trials on their land), they have attended workshops and attended cross-site visits. This has often led to village meetings being held independently of the project, with farmers sharing their experiences.

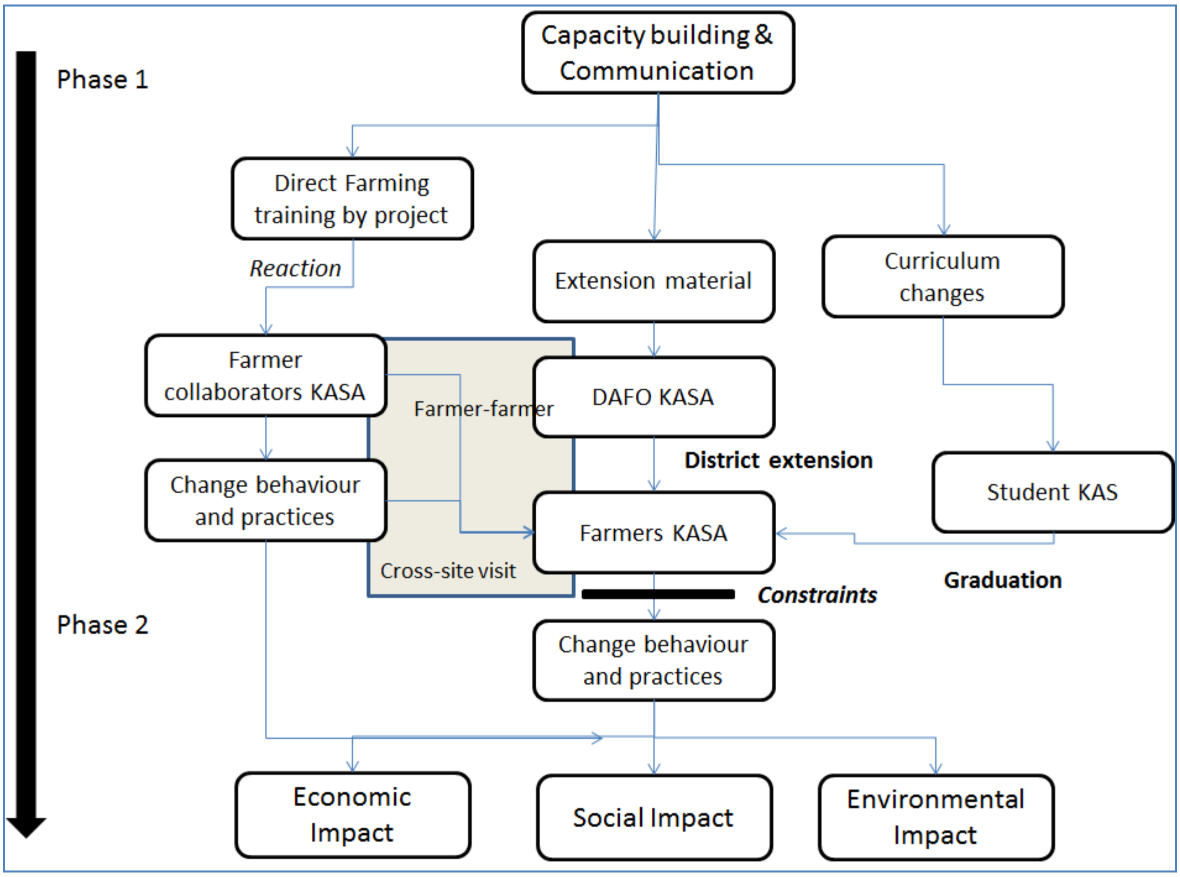

Figure 8.1: Impact pathways of capacity building and communication. (KASA = Knowledge, Attitudes, Skills and Aspirations)

The on-going development of extension material together with training days and cross-site visits is seen as the main pathway to increase adoption of new practices by smallholder farmers. The capacity that has been established through the first phase of the project (including the skills of staff and the development of a network of demonstration sites) will allow the government (NAFReC, PAFO and DAFO) and other organisations to continue to provide these services. However, it is well understood that this will be difficult to accomplish outside a project or program that provides continuing financial and technical support. Reporting of results to other projects and NGOs is seen as a means of building on the initial investment.

Follow up surveys with farmers, village heads and technical staff have identified that there are still several constraints to adoption and thus final impact (economic, social and environmental). These relate to the long-term nature of the benefits, in particular the limited market for small dimension logs obtained from thinning of highly stocked teak woodlots is a major constraint to adoption of thinning in established woodlots. Labour constraints are still reported by farmers as the main reason for non-adoption, as without a commercial market for small logs there is no return on labour from thinning. However, this illustrates the need to demonstrate that the longer-term economic returns to labour are high and worth the investment, a task that has been made easier by the creation of the network of thinning trials.

While the potential pathways are outlined above, there is a need for ongoing research, particularly related to agroforestry systems that provide an income source during the early years. The genetic improvements established under this phase of the project are still undergoing development and may deliver a commercialisation pathway over the next phase and beyond.

8.1.1 Capacity of teak farmers

A series of farmer training events was conducted by project staff in 11 locations in 2010-2011. The training events directly involved the training of 321 farmers from 18 villages from Luang Prabang province. The events were attended by both men (245) and women (76) farmers (Table 8.1) and included farmers from several ethnic groups. The records of participants also show that the trainees were representative of the population in terms of teak holding size, with farmers having small and large woodlots attending. Farmers without teak were also present at some of the training events.

Prior to each training session farmers were surveyed about their teak holdings and current knowledge on thinning and pruning, including perceived benefits and the methods and timing of each operation. The questionnaire was repeated at the end of the training day to monitor changes in awareness and plans for future management.


Figure 8.2: Staff from NAFReC providing training on thinning and pruning in 2010. The training included discussions and village meetings followed by field walks to further discuss the appropriate methods and timing of silvicultural management.

With the exception of training provided at Ban Kok Ngiew, these training days were usually the first training event that participants had attended related to teak management. This was apparent with the lack of knowledge on the appropriate timing and methods for key silvicultural practices such as thinning and pruning. Before the training days, many farmers considered thinning to be the removal of the best trees that already had a commercial value (i.e. thinning from above). A large change in knowledge has been achieved in that farmers now understand the concept of thinning from below through the removal of small, suppressed trees, trees too close to another tree, and singling (to reducing trees with multiple stems a single main stem). Having said this, follow-up training events to highlight the importance of early thinning are still required, with return visits to thinning plots to discuss growth rates of various treatments.

Farmers were asked at the end of the training whether they were planning to do any thinning and pruning in the coming year. While around two-thirds said that they would carry out some recommended management practices, the level of adoption at this stage is anticipated to be lower, even among those who participated in the workshops. Farmers mentioned the time required as the main reason for not adopting. With the demonstration sites now showing results that are observable, it is expected that adoption would increase with follow-up workshops and site visits. However, getting farmers to thin early is the main on-going challenge. Interviews conducted at the end of the project have shown that other farmers within the villages are aware of the demonstration trials and have spoken to others in the village. However, now that the impacts of treatments are more apparent, facilitated farmer field days and cross-site visits would be useful to ensure that the key messages are being shared.

Table 8.1: Location of farmer training events in 2010 and 2011

Training	Location of training	Attended	Male/ female	Ethnic Group (male/female where recorded)	Villages involved
2010 Training					
1	Xienglom	25	14/11	Lao 25	Xienglom, Phik Noi
2	Kok Ngiew	24	16/8	Lao 12, Khmu 12	Kok Ngiew, Ban Ean
3	Dansavang	30	29/1	Lao 15, Khmu 15	Deansavang, Phik Ngai
4	Sanok	17	8/9	Lao 12, Hmong 3, Khmu 2	Sanok, Khok samoi
5	Phatonglom	27	27/0	Lao 5, Khmu 22	Phatonglom, Dan, Namphak
6	Lak Sip	33	20/13	Lao 1, Khmu 32	Laksip
2011 Training					

1	Phonsavang	33	22/11	Lao 4/6, Khmu 18/5	Phonsavang XiengGnuen
2	Donmo	24	29/4	Lao 19/3, Khmu 1/, Kmo 9/1	Donmo
3	Suandala	50	38/12	Lao 21/8, Khmu 1/1, Kmo 16/3	Suandala
4	Sibounhome	35	32/3	Lao12/2, Hmong 9/1, Khmu 11/0	Sibounhome
5	Phonsavang (Pak Ou)	23	19/4	Lao 11/3, Khmu 8/1	Phonsavang (Pak Ou)

8.2 Scientific impacts – now and in 5 years

8.2.1 Teak Silviculture and Agroforestry Research

Research on teak silviculture and agroforestry systems requires a number of years to obtain useful scientific results. As such results were not available until the completion of the project to enable the publication of results, and consequently there have been limited scientific impacts to date outside the project. However, the project has established a scientific basis for recommending initial stocking rates and early thinning regimes in order to maximise girth growth rates and as a result overall stand value. Another significant scientific impact is the development of various teak growth models, including: predictive tree volume equations; a model to predict the mean diameter of teak stands based on measurements of age, mean stand height and stocking; and a series of site index models for young teak plantations in the Luang Prabang region of northern Laos. Two different site index models have been developed using a base age of 15 years: site index curves using the mean height of teak stands for site indices from 11 to 19; and site index curves using the predominant height of teak stands for site indices from 15 to 23.

In addition, the project has demonstrated preliminary scientific evidence on optimal establishment stockings as well as the results from thinning stands of teak that have been established at high initial stocking rates. Near optimum growth rates for both height and girth occurs when the initial spacing is in the range of 600-800 sph, rather than at the current recommended planting rate of 1100 sph. When thinning was conducted in stands less than 10 years of age, there was generally an improved girth increment across all tree sizes. However, thinning of the older stands resulted in an improvement in the girth increment only in the largest (i.e. dominant) trees in the stands. Further, there were clear differences in the girth increments observed between the younger and older stands – with relatively even growth increments in the younger stands, while in the older stands the largest trees (dominant) had 2-4 times the growth increment of the smaller (suppressed, sub-dominant and co-dominant) trees.

The results from the farmer-based agroforestry trials showed that annual cropping in the initial four years of an agroforestry system can provide cash income; however, the returns to household labour are low and variable when the prices for agricultural products are unstable. Better designed agroforestry systems have greater potential to deliver higher incomes and for a longer period.

In the next 12 months we anticipate submitting for publication in refereed journals publications detailing: impacts of initial stocking in Nelder wheels (preliminary results were reported at the World Teak Conference in Bangkok in 2013, and results from first year of intercropping will be reported at the World Congress on Agroforestry at New Delhi in February 2014); inventory of teak smallholder woodlots; development of volume equations and site index functions for young teak in Luang Prabang; and the impacts of thinning in highly stocked teak woodlots. We aim to publish results in both English and Lao languages, with key results reported in the Lao Journal of Agriculture and Forestry, as this journal is widely distributed through the district agriculture and forestry offices (DAFO) in Laos. As such, we believe this is the best way to distribute key results of the project to the people (DAFO staff) who are the primary source of extension information for the smallholder farmers. Scientific impacts are expected within the next 5 years as results become available through scientific literature through ACIAR.

8.2.2 Teak Genetic Improvement Research

Genetic improvement of teak is again a long-term exercise. The successful application of grafting for the propagation of selected, mature teak trees has also now been applied as part of the The Agrobiodiversity Initiative (TABI - http://www.tabi.la/) in Lao to preserve germplasm of Myanmar teak.

8.2.3 Socio-Economic Research

The research on the livelihoods of teak households has resulted in an appreciation of the complexity of the upland farming systems and wider agrarian systems in which teak farming occurs. Socio-economic research found that teak planting has been more extensive among households with a longer history of settlement, where the household head was older and better educated, where household members had off-farm sources of income, and where the household had access to paddy land and so was thus more likely to be self-sufficient in rice. For these households, teak planting presents a land-use option that requires less labour input and, if managed effectively, can substantially improve household income. For households that depend on shifting cultivation for their livelihoods, they generally borrow land for upland rice production on the condition that after harvest they established teak for the owner. As the area of land under teak expands these households have to go further afield to obtain land for rice production.

The publication of the research results in conference proceedings, international journals, and posters has been accessed by local and international researchers, consultants working in Laos developing strategies on upland farming systems and policy makers. The paper on agrarian change was cited by the keynote speakers of the Livelihood Symposium at the World Teak Conference in Bangkok (Nair 2013), where it was used to highlight that the ability of smallholders to improve their livelihoods through teak farming depends on various socio-economic factors.

8.3 Capacity impacts – now and in 5 years

The improved capacity of the research partners and stakeholders to conduct and deliver ongoing research and extension that will enable the adoption of improved management practices has been a major outcome of the project. Furthermore, through training activities conducted by the project team, the capacity of 321 farmers from 18 villages from Luang Prabang province has already been enhanced with a better understanding of appropriate silvicultural practices and alternative teak-based systems. These achievements have built the platform for ongoing work both within future ACIAR projects and other projects and programs.

8.3.1 Training and extension infrastructure

A major objective of the project was to establish a network of thinning trials throughout Luang Prabang province that could be utilised for both research and extension. As such, the project has created a legacy of demonstration sites that can be utilised for both ongoing research and as key learning sites for extension activities. A network of thinning trials now exists in 12 villages across 4 districts of Luang Prabang province. Observability of the benefits of management change is one of the key variables that influence adoption. This network has greatly increased the ability for farmers to observe of the relative advantage of management changes.

Ongoing utilisation of this infrastructure through subsequent ACIAR projects and other government and NGO initiatives will contribute to the adoption of improved management practices. Similarly, the Nelder wheels have been an investment in future research and learning activities. Students at the Northern Agriculture and Forestry College across several years have been involved in taking measurements from the demonstration trial. The Nelder wheel will be a legacy of the project that will last for many years and be utilised by students, staff, and farmers.

8.3.2 Other infrastructure

The project invested in the development of nursery facilities for the propagation of teak and non-timber forest species at NAFReC Houay Khot and Thong Khang research stations, at on the Souphanouvong University campus. Office facilities were upgraded for project staff based at the Houay Khot. In conjunction with the current project and additional Small Research Activity, we commenced the redevelopment of tissue culture facilities – conversion of existing laboratory space at Souphanouvong University and installation of air conditioners in new growth room, upgrading of tissue culture facilities at the Agriculture Research Center (Naphok) by replacing the ceiling and installation of new air conditioners in the growth room, and development of plans for construction of tissue culture laboratory at NAFReC Houay Khot. Further, facilities at the Thong Khang Agroforestry Station were also upgrade – installation of new water pump and pipes supply water to the station, replacement of roof and ceiling in the dining room and renovation of visitors quarters to enable researchers to spend periods staying close to the research trials. These improvements to the infrastructure will provide ongoing benefits to research in northern Laos, and be utilised as part of the follow-on project.

Equipment supplied through the project includes: vehicles – two four wheel drive dual cab utility vehicles, three Honda motor cycles, computers (one desktop and 5 laptop computers), measurement equipment (3 Vertex Hypsometers, 1 x Nikon hypsometer, 3 handheld GPS, plus various other equipment), pruning saws, grafting equipment and digital cameras. The infrastructure now enables local staff to establish, maintain and measure diverse field experiments in the region.

8.3.3 Staff training

The Lao project staff members have been involved in both formal and informal training that includes:

- Establishment and measurement of field trials
- Propagation of teak by cuttings
- Propagation of teak by tissue culture (Khon Khan University and Naphok)
- Statistical analysis of data (Crawford Fund training)
- Report writing (Crawford Fund Training)

- Attendance of six researchers at the World Teak Conference in Bangkok in 2013

8.4 Community impacts – now and in 5 years

The outcomes are the changes in practice, products or policy that result from the adoption of the outputs. Intermediate outcomes require additional investment to generate changes in practice, products or policy that have community outcomes. They are important measures of progress toward achieving final outcomes and consequently impact, but in themselves do not generate impacts. An example is the stock of knowledge. There may be a threshold level of knowledge, skills and capabilities needed in a research organisation before it can generate information or products that are applicable to local farmers. The intermediate outcome is the increase in the stock of knowledge; the output of the application of this knowledge might be a new variety of crop that has a higher yield or improved resistance to disease. Adoption of this output then leads to a final outcome.

As noted earlier, the current outputs of the project have mostly led to intermediate outcomes. Typically, these intermediate outcomes require additional investment to generate changes in practice, products, or policy that will have community outcomes. Nevertheless, these are important milestones in the progress toward achieving final outcomes and consequently economic, social and environmental impacts.

8.4.1 Economic impacts

Spacing and Thinning

There is a strong local, domestic and international market for teak timber produced from sustainably managed plantations. Individual trees are sold for as little as US$10-15 for small, young trees and up to US$300-400/tree for large trees around 25-30 years of age, with an average price of around US$50/$m^3$ at the stump. Individual trees can be harvested to meet periodic household expenses (e.g., education, marriage, sickness) without the need to sell the entire woodlot and the land on which it is growing. Consequently, the estimated 20,000ha of smallholder teak in Luang Prabang represents a significant resource in this region. Annual increments of smallholder woodlots in Luang Prabang averaged 10m^3/ha/yr in our study. When multiplied across a 20,000 ha teak resource this represents an annual increment of $10 million in value. For an individual smallholder with 0.2 to 1.0 ha of teak, an annual increment of 10m^3/ha/yr represents an additional value of $100 to $500 each year.

Results from the current study indicate that total productivity per hectare may not be improved by thinning (i.e. annual increments probably remain around 10m^3/ha/yr after thinning); however, thinning from below will redistribute this increment to favour growth of the larger, more valuable trees. Consequently, even if the total volume of wood produced by a smallholder teak woodlot remains largely unchanged following thinning, the value of retained individual trees will be much higher due to having larger diameters. The increment in value per tree resulting from thinning may double or triple the standing value of a well-managed teak woodlot (i.e. fewer, large rapidly growing trees) compared to a poorly managed, highly stocked woodlot (i.e. the status quo, with a large number small trees, most of which are growing slowly and becoming increasingly suppressed). This value proposition will be quantified over the next phase of this research.

Economic benefits are expected to accrue to smallholders from adoption of improved silvicultural management at three intervention points: i) a reduction in the initial stocking rates, ii) adoption of non-commercial thinning in young stands (from around 5-6 years after planting), and iii) the thinning of over-stocked older (10-16 years). Adoption of much lower initial stocking rates (i.e. approximately 600 trees per hectare compared to 1100 or more trees per hectare), will reduce the cost of establishing teak woodlots as many less trees need to be grown or purchased as well as reducing labour requirement for planting and follow-up maintenance. Results from Nelder wheel trials indicated these greatly reduced stocking rates will maximise tree growth, and potentially allow a much longer period of intercropping with the developing teak and bring forward the age at which the first commercial returns can be obtained from harvesting trees. Implementation of non-commercial thinning in young plantations (i.e. to remove around one third of the trees to reduce stocking to around 600-700 sph) will require relatively low labour inputs as the trees are small, and so farmers may be more willing to conduct a thinning at this stage of the stand development. Results indicate that interventions at this stage will result in improved growth rates of the retained trees, improved stand quality (by removing poor trees), increased tree size, and improved stand health (by removing suppressed and dying trees. The third intervention point is probably the least likely, due to the lack of markets for trees that must be thinned, yet are not large enough to be used as sawn timber. At this stage (10-16 years of age) thinning also requires a significantly greater labour investment to remove 300 to 400 trees per hectare, with little immediate economic return to labour. Many farmers are also very reluctant to remove trees at this stage, because they believe that they will become saleable in a few years; however, data collected indicates that this belief is without foundation as the sub-dominant trees in the smallholder woodlots are growing very slowly, and becoming increasingly suppressed over time, and so may never reach a size that will enable them to be sold into the sawn timber market. Therefore, smallholder farmers in this situation must either find alternative markets for small dimension logs (e.g. poles for construction or charcoal) or must be convinced that the labour investment in thinning today, will lead to improved income from their woodlot in 5 to 10 years.

Economic impacts from adoption of much lower initial stocking rates is the most likely to be realised by smallholders in Luang Prabang in the short term. Surveys carried out and interviews conducted at training events have shown that the majority of farmers have woodlots established at an initial spacing of 2x2 and 3x3 metres (i.e. between 1100 and 2500 sph). These heavily stocked woodlots under current management have led to slow annual increments in value. The research results have already led to changes recommended in stocking rates, with partners now proposing much wider initial spacing (e.g., 4x4 metres or 625 sph at establishment). These changes will be reflected in changes to the curriculum at Souphanouvong University and the Northern Agriculture and Forestry College, and in extension materials that will be prepared by NAFReC for distribution to smallholders through the PAFO and DAFO staff. Within the next 5 years we would expect that substantially lower planting rates will be common, and so largely eliminating the production of small dimension logs in smallholder woodlots. We would also anticipate that early thinning (at 5-6 years after planting) will also become more common as information is distributed to farmers of the next few years – as indicated above, labour required is relatively small. As can be seen from Figure 9.1, there is a large area of smallholder teak established since 2005 that now requires thinning, and should be target of future extension and training. The major problem will be with the large number of woodlots planted before 2003 that are either unthinned or which have been thinned from above (removing the best formed and fastest growing trees) – refer to Figure 9.1. Bringing these stands down to appropriate stocking levels will require new markets for small dimension log as has occurred through the work of the Luang Prabang Teak Project and the Tropical Forestry Trust. Nevertheless, there will continue to be a significant number of teak owners who will leave their woodlots unthinned and overstocked because their primary interest is not growing trees but rather capital growth in land value. For these people, teak (once established) requires little (if any) management inputs, with good long term prospects for capital growth.

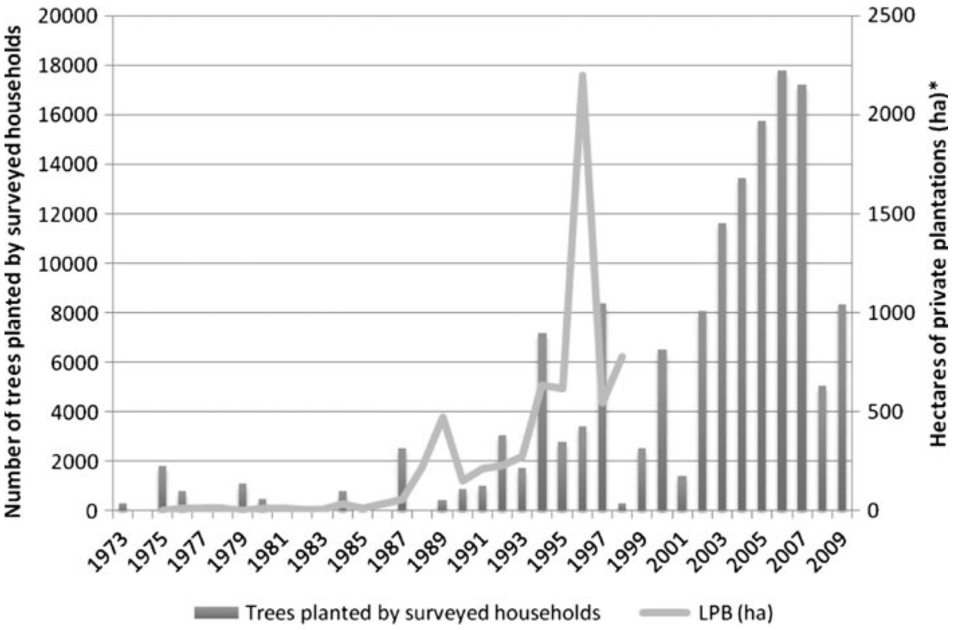

Figure 9.1: Number of teak trees planted by survey respondents annually (1973–2009) compared with Kolmert's 2001 data on area of teak planted in Luang Prabang Province (1975–1998) (Source: Newby et al. 2012).

Agroforestry

Surveys and case studies identified agroforestry systems being adopted by some households. These systems include cash crops (corn, Job's tears, bananas) and NTFPs (paper mulberry [*po sa*] and broom grass) grown as companion crops with teak. Returns to labour remain an important consideration for these households, although providing a more stable income stream from the whole farming system is essential to enable adoption. The surveys also revealed some households that had invested in woodlots and as a result had become land-constrained, leading to a need to rent additional land and/or distressed sales of woodlots to deal with household shocks. These households may have benefited from adopting alternative systems with short-term cash flows.

Agroforestry systems involving teak represent a different management system for growing teak in northern Laos. By using much lower initial stockings (e.g., 600 trees/ha, compared to 1100+ trees/ha), the initial cost of planting stock is much lower and adoption of much lower stocking rates will extend the window where trees and companion crops (e.g., upland rice) can be grown together economically. Diameter increments of around 4 cm/year were measured in Nelder wheel trials from the third growing season and also in smallholder plantations at 5-6 years of age. If diameter increments of this magnitude can be maintained, it will be possible to produce trees meeting minimum size standards (20-30 cm in diameter) by 8-10 years compared to the current 12-15 years.

Agroforestry systems that can maintain annual incomes from smallholder land, and allow tree crops to be harvested as much as four years earlier, will have significant economic benefits to smallholders. Given that the opportunity cost of capital is very high (e.g., in some villages farmers pay 3% per month for funds from saving groups), bringing additional benefits forward in the time horizon is an attractive option for smallholder. Preliminary trials of various agroforestry systems in Phonsavang village demonstrate household earnings of up to 1.5 million kip per year from combinations of bananas, paper mulberry, broom grass and Job's tears. However, case studies revealed that households remain exposed to both market and production risk from these systems. Improved agronomic and market research may be necessary to minimise these risks. On-going research is required to develop these systems, to allow smallholders with less resources (e.g. land and off-farm income) to take advantage of the longer-term benefits of growing tree crops such as teak.

8.4.2 Social impacts

Teak planting to date has been more extensive among households with a longer history of settlement, where the household head is older and better educated, where household members have off-farm sources of income, and where the household has access to paddy land and is thus more likely to be self-sufficient in rice. For these households, teak planting presents a land-use option that requires less labour input and, if managed effectively, can substantially improve household income. For other households, the adoption and maintenance of teak woodlots has been difficult.

The research into agroforestry systems has shown that is possible to maintain income from upland fields during the early years of establishment. Although further research is required, this suggests that alternative teak-based systems may increase the ability for households with lower resource access to diversify their farming systems to include teak and other tree crops.

Improved management of the existing woodlots and associated higher incomes is likely to improve the social outcomes of households. While it is recognised that money is fungible, households still view teak as a saving account that is often associated with a future investment in the education of children where large lump sums of money are often required for school fees. In the absence of other financial services, this has been a critical role of investments in trees (as well as livestock).

8.4.3 Environmental impacts

Under current management of teak woodlots, there is high risk of soil erosion especially on sloping land. High stocking rates preclude the development of an understorey as a consequence of the dense canopy. Teak management systems involving much lower stocking rates will allow an understorey component to develop under established teak, or in the case of widely spaced teak-based agroforestry systems, contour planting will lead to alternating strips vegetation and cultivated land. Both strategies have great potential to stabilise the soil on sloping land, and minimise the risk of soil erosion.

8.5 Communication and dissemination activities

A range of communication activities have carried information directly or indirectly to teak farmers and other stakeholders that have and will continue to provide information to final users. These have included academic journals articles, conference paper, posters, and training manuals.

Project meetings each year involved participants from PAFO, DAFO, and representatives from villages. These meetings were useful to provide some of the initial results to key partners. However, they also highlighted the need for the complex scientific data to now be translated into a format that would be easily understood by extension staff and farmers. One example was the need to move away from average diameters and mean annual increments when discussing the potential economic impacts of various management practices.

8.5.1 Conferences and workshops

Newby JC, Cramb RA and McNamara S (2010). Smallholder teak and agrarian change in Northern Laos, Paper presented at the International Conference of Revisiting Agrarian Transformation in Southeast Asia: Empirical, Theoretical and Applied Perspectives, Research Centre for Sustainable Development, Chiang Mai University, Chang Mai.

Newby JC, Cramb RA, Sakanphet S (2013)[7]. Looking beyond the woodlot. Poster paper presented at the World Teak Conference, 25th – 30th March 2013, Bangkok, Thailand.

Souliyasack B, Sakanphet S and Dieters M (2013). Growth and form of teak in a Nelder wheel in Luang Prabang, Lao PDR. Poster paper presented at the World Teak Conference, 25th – 30th March 2013, Bangkok, Thailand.

8.5.2 Publications

Newby JC, Cramb RA, Sakanphet S and McNamara S (2012). Smallholder teak and agrarian change in northern Laos. *Small-Scale Forestry* 11(1):27–46

[7] *Refer to Appendix 11.1 for copies of posters presented at the Teak World Conference, March 2013.*

9 Conclusions and recommendations

9.1 Conclusions

Nelder Wheel

Initial stocking has a significant impact on the growth and development of teak, as demonstrated in the Nelder wheel at the Northern Agriculture and Forestry College, where the impacts of differences in the initial stocking became evident from the fourth growing season. Comparison of results between the fourth and fifth growing seasons demonstrated that annual increments in mean height, diameter and volume maximised at a lower initial stockings in each successive season. This suggests that growth rates can be maximised in the first 4-6 years after planting by using initial stockings between 600-800 sph. Further, if growth rates continue to optimise at lower initial stocking rates in successive years, this implies that woodlots established at stocking rates over 600 sph will require early thinning to maintain rapid early growth rates. Likewise, for woodlots established at higher stocking levels, the results imply that inter-tree competition is significantly (adversely) impacting on growth increments from as early as the fifth growing season. Consequently, thinning as early as the end of the fourth growing season may be required if adverse impacts on tree growth are to be avoided.

The value of individual teak logs in Luang Prabang is primarily determined by tree size. In the fifth growing season the average girth increment at the optimal stocking (± 600 sph) of the Nelder wheel was approximately 9 cm/yr. Increments of this order, suggest that on average trees will change from one 10cm girth class to the next in most years, and so represents a significant increment in value annually. Similarly at this stocking, trees averaged approximately 35 cm in girth by end of the fifth growing season, and so could be expected to reach minimum commercial sizes by as early as the end of the sixth growing season.

This suggests that woodlots established as initial stocking rates of around 600 sph may largely eliminate the requirement for non-commercial thinning, since most trees will reach minimum commercial size within 8-10 years after planting. Therefore, trees removed in a first thinning at around this age may well be sold into the local market as minimum dimension sawlogs. Although the value of such young sawlogs is likely to be low (due to a low proportion of heartwood), such logs can be sold and so these lower initial stocking rates have the potential to reduce the time from planting to the first commercial return to as little as six years. Narrowing the window from planting to first commercial harvest has many potential benefits – reducing the risk that the smallholder will be forced to sell both land and trees to meet short-term financial shocks when their woodlots are young, and reducing the period when the smallholder requires access to alternate land or other resources to meet household budgets while the trees are maturing. Growing teak at much lower stocking rates (i.e. around 600 sph) will also approximately halve the requirement for planting stock thereby lowering the cash investment required to purchase seedlings, and permit greater incorporation of crops into teak-based agroforestry systems.

Teak Smallholder Woodlots

Most smallholder teak woodlots in Luang Prabang up to 16 years of age, are currently standing at very high stockings, with over 90% of stands measured exceeding the initial stocking rate of 1100 sph that is currently recommended by the PAFO in Luang Prabang.

This most probably reflects poor dissemination of information to smallholder farmers and misconceptions by farmers relating to stand value. There is clear need for information to assist smallholder to better manage stocking levels in their teak woodlots.

The site index (SI) equations developed provide a means to compare the quality of sites in terms of their suitability for growing teak. The average site index of woodlots measured was close to 19 across all age groups, indicating an “average” site has a predominant height of 19m at 15 years of age. However there was substantial variation in the predicted SI, ranging from approximately 14 to 24, indicating significant variation in the potential of different sites in Luang Prabang province for the growth of teak. Differences of 8m in mean height are projected between the lowest and highest site index classes at 15 years after planting. This suggests a need to develop better guidelines to assist smallholders determine the suitability of their land for conversion to teak woodlots. Careful site selection and/or use of appropriate nutrient regimes have the potential to greatly improve productivity of teak in many smallholder woodlots. However, the opportunity cost of converting the most suitable (agricultural) land to woodlots needs to be considered.

An observed decline in the mean stocking level in stands aged 14-16 years in the farm-based trials, is most probably due to mortality. No stands that had been previously thinned were included in this study, and typically smallholders do not start to thin woodlots until around 15 years after planting. Reduction in stocking rates from mortality implies high levels of inter-tree competition.

Mean annual increments in the farm-based trials, estimated by dividing the measured diameter, height, and volume of each plot by its age, on average are approximately 1cm/year in diameter, 1 m/year in height and 10-11 m^3/ha/year in standing volume. Nevertheless, there was considerable variation in these averages, and high productivity (m^3/ha/yr) was not related to stocking.

Growth rates (i.e. current annual increments) observed in the Nelder wheel through to the end of the fifth growing season under optimal stocking regime (± 600 sph) greatly exceeded girth increments commonly observed in the smallholder woodlots measured. In the first case, increments approached 9 cm/yr in girth, while in the measured smallholder woodlots girth increments did not typically exceed 3 cm/yr, with average increments and increments observed in most girth classes often closer to 1 cm/yr. This represents a very significant difference in productivity between that achieved in the Nelder wheel and that realised in the farmers’ woodlots. Differences to some extent will reflect differences in site quality, but also the impacts of stocking as demonstrated in the Nelder wheel where girth increments were less than 3 cm/yr at stocking rates of 1600 sph or higher.

Average standing basal areas maximised at approximately 21 m^2/ha; although individual plots had basal areas of up to 30 m^2/ha. This combined with the observed decline in stocking levels (see above) in older stands, suggest stand management should target maximum basal areas between 20-25 m^2/ha to maintain productivity and stand health.

Thinning trials

The distribution of growth (i.e. girth increments) within teak stands (i.e. among trees within a stand) maintained at high stockings for 10 or more years was highly skewed. The largest (dominant) trees in these stands are growing 2-4 times faster than the remaining trees in the stand. This suggests that any form of thinning that removes the dominant or co-dominant trees from these teak stands will adversely impact on the future growth potential of the stand. Therefore, thinning from above should be strongly discouraged through the development of appropriate extension materials.

Very slow growth rates (i.e. current annual girth increments) were measured on the sub-dominant component of trees in smallholder woodlots of Luang Prabang that had been maintained at high stockings beyond 10 years of age. This indicates that retention of these subdominant trees over the short to medium term will result in little additional value increment, and may restrict the growth capacity of the larger (dominant, high value) trees in the stand and reduce stand value as a consequence of mortality.

Limited response to thinning, particularly in stands 10-16 years of age when first thinned, suggests that much heavier thinning than that applied in this study is required. Many of the retained trees in the thinned plots subsequently demonstrated signs of suppression (e.g. crown damage, loss of dominance, etc.) and showed no (or very little) capacity to respond to thinning. Retention of such trees in unlikely to result in improved stand value over time, as they have little capacity to increment in value.

Basal area, rather than stocking, may be a more appropriate method to use to determine thinning regimes. Regimes based on maintaining stand basal area will take account of the large differences in site quality observed in the teak woodlots used in this study, and allow broader application of results. Training in use of simple methods to determine stand basal area is however required if thinning regimes are determined by basal area rather than stocking at a given age. The use of basal area limits would have the additional benefit in that farmers can then use stand volume equations to track increments in their woodlots without the need to establish plots or measure a large number of trees.

Implementation of non-commercial thinning of older, highly stocked teak woodlots is likely to be problematic. Adoption will require supporting extension and training materials to assist farmers understand the future benefits of thinning to stand value. Nevertheless, it will be difficult get farmers to invest labour in the thinning of their woodlots unless they can receive a tangible financial benefit from the trees that are removed. Alternate markets for small dimension teak logs are required—possibly the production of charcoal from teak may be a viable option.

As an alternative to non-commercial thinning, adoption of much lower initial stocking rates (e.g. 600-800 sph using spacing such as 4 x 4 m) and perhaps rectangular spacing such as 5 x 2.5 m (800 sph), 6 x 2.5 m (667 sph) or 8 x 2 m (625 sph), may mean that almost all planted trees will have the potential to reach the minimum size for small sawlogs within 8–10 years after planting. If so, then a first thinning could remove minimum size/quality sawlogs (most probably for the domestic market), and subsequent thinning operations can then produce higher value, larger dimension logs for sale in either the local or external markets.

Agroforestry Trials

The agroforestry trials have demonstrated that it is possible to successfully establish teak using widely spaced (paired or single) rows of teak aligned along the contour, and provide the farmers with cash income in the initial four years from the companion crops. However, returns to household labour were low, and possibly less than the shadow wage rate. A major component of the labour inputs was weeding, with farmers reporting increasing weed problems in the second and third years following establishment. The establishment of perennial crops such as banana and NTFPs provided good returns to labour, at least up until year four.

These preliminary trials demonstrate the potential of agroforestry systems to deliver annual incomes to the smallholder farmer over a longer period than using the conventional initial spacing 3 x 3 m for the teak trees. Wider spacing between teak rows and better designed systems will potentially deliver higher incomes over a longer period; however, more research and extension is required to develop and demonstrate a range of agroforestry and silvo-pastoral systems.

Further, given that farmers are subject to marketing costs and marketing risk, there may be potential to improve farm incomes by utilising some form of farmer organisations to share marketing costs. This may include collective post-harvest activities such as drying, transport and sales.

Genetic Improvement of Teak

Propagation by cuttings directly from mature trees proved to be very difficult under prevailing conditions in Laos, while propagation by grafting was relatively easy and simple. Grafting was used to establish selected teak trees in clone banks, seed orchards and hedges.

The high success rate obtained using grafting, indicates that this work can be readily expanded to ensure that a larger genetic base of teak is accumulated and preserved in clone banks in Laos. This could include samples of trees selected in the native stands.

Propagation of improved quality teak germplasm by cuttings or tissue culture is expected to be more successful using material collected from these grafted plants as a consequence of the better quality shoot material that will be produced. Hedges of the best selected teak trees should be established at both Naphok and Houay Khot to facilitate future vegetative propagation of teak using both tissue culture and cuttings.

Socio-Economic Research

Within the study area several overlapping influences have induced the overall land-use change associated with the establishment of tree-based farming systems. However, there is a spectrum of farming and livelihood systems between the two extremes of absentee urban-based landowners who have acquired teak holdings and the rural households that have recently been relocated from more remote upland areas and who remain highly dependent on swidden agriculture. These systems are managed by households with a variety of livelihood platforms, responding dynamically to different opportunities and constraints as they arise. These include variations in land types and productivity, population growth, access to land, access to markets, non-farm employment opportunities and *ad hoc* policy changes.

The case studies revealed that land-use change occurring at the household scale is following different pathways, even for households in the same village occupying adjacent parcels of land. At the same time, these households are by no means on smooth, continuous “pathways”; the predominant trends are punctuated by unanticipated shocks that have significant and long-lasting impacts on households that are often living on the margin. Three of the pathways identified by Lambin and Meyfroidt (2010) were clearly distinguishable and relevant to current research and extension activities – an economic development pathway, a smallholder intensification pathway and a state policy pathway.

The research shows that the establishment and improvement of teak woodlots and agroforestry systems aimed at providing a “pathway out of poverty”, needs to be seen in the context of household livelihoods and processes of agrarian change and differentiation to appreciate the various impacts on livelihood trajectories. Given the large diversity in livelihood platforms in the target villages, extension materials on stocking, spacing, companion crops and management need to capture the diversity of household situations and be targeted accordingly.

9.2 Recommendations

The following six recommendations are made based on the findings from the research conducted under this project.

Recommendation 1

Increase the initial spacing of teak in smallholder woodlots from the 3 x 3 m (1100 sph) that is currently recommended, to a spacing that provides an initial stocking of between 600 and a maximum 800 trees per hectare. For establishment on relatively flat land (i.e. slopes less than 10°), and where the farmer is primarily interested in growing teak, a square spacing of 4 x 4 m (giving and initial stocking of 625 trees per hectare) is recommended. However, on sloping land or where the grower is also interested in companion crops, then contour planting of the teak and use of a rectangular spacing such as 6 x 2.5 m (667 sph) or 8 x 2 m (625 sph) is recommended. Rectangular spacing such as these that yield an initial stocking between 600 and 700 trees per hectare, will allow vegetation to grow (or be grown, e.g. a companion crop or fodder crop) in the inter-row along the contour providing greater soil protection and so reduce the potential for erosion. Reduction of the initial stocking rates will reduce the cost of establishing teak woodlots (i.e. less plants need to be purchased and less maintenance is required during establishment), and is expected to largely eliminate the production of small dimension logs in smallholder woodlots. Nevertheless, a non-commercial thinning is still likely to be required within 5-6 years after planting, especially for woodlots established at the higher end of the recommend range (i.e. around 800 trees per hectare). Well-managed, woodlots established at these lower stocking rates are likely to yield a first commercial harvest by thinning from below (i.e. removing the smallest rather than the largest trees) within 10-15 years (depending on site quality).

Recommendation 2

Non-commercial thinning of established highly stocked woodlots aged up to 8-10 years of age is recommended. Thinning trials demonstrated a good response (i.e. improved girth increment) across all size classes in the retained trees when thinning was conducted at this age. Non-commercial thinning should ideally be conducted 5-7 years after planting and aim for a residual stocking of around 600 stems per hectare. The thinning should be from “below”, removing the smallest trees, and removing trees with obvious defects (crooked, forks, broken tops, etc.) and reducing trees with multiple stems to a single dominant stem (i.e. ‘singling’). Implementation of pruning to a height of 2-3m above ground, of all retained stems following this non-commercial thinning, is also likely to be beneficial; however, the benefits of pruning need to be investigated. Further, it is expected the non-commercial thinning of these stands will help to maintain high current annual increments in these stands, and largely prevent creation of a suppressed and stagnated component of trees as the stands age.

Recommendation 3

Thinning of established woodlots aged over 10 years of age requires development of markets for small-dimension logs, to facilitate and encourage thinning (from below) of these woodlots. Many of the existing smallholder woodlots are very highly stocked (over 1700 sph), and a large proportion of the trees in these woodlots are growing very slowly (current annual girth increments of less 1 cm/year) with the large, dominant trees in these woodlots contributing most of the volume increment in these stands. Consequently, it is recommended that the current practice of thinning these stands from “above” (i.e. removing the large, dominant, fast-growing trees of highest value) be strongly discouraged through the development of extension materials, such that farmers can make informed decisions about the management of their teak. Research underpinning the development of alternative markets for small dimension logs (e.g. charcoal production or as poles for use in construction) is required.

Recommendation 4

Teak-based agroforestry systems require further investigation and development. These systems have the potential to deliver annual incomes to smallholder farmers through the cultivation of companion crops, and successfully establish a well-stocked and actively growing teak woodlot. Weed control is a major component of labour inputs, particularly in the second and subsequent growing seasons, and research is required on systems that are able to provide higher returns to labour. This may be achieved through the adoption of more widely spaced teak and establishment of companion crops in the centre of the inter-rows to maximise the productivity of both crops; or perhaps temporal separation of the establishment of the teak and a companion crop(s). Additional research and extension activities are recommended to develop these systems to a stage that they can be readily adopted by smallholders.

Recommendation 5

Genetic improvement of teak is fundamental to maintaining high quality trees at the reduced stocking rates that are recommended above. Poor quality planting stock requires higher initial stocking rates and early non-commercial thinning to ensure an effective stocking of high quality trees. Methods to rapidly select and propagate superior teak genotypes are required. Results obtained suggest that initial propagation of selected (mature) trees using grafting is able to efficiently capture and preserve elite teak clones. Nevertheless careful maintenance of the grafted trees is required to ensure that the stock plants do not replace the grafted scions. Grafted trees are seen as a first step in the propagation cycle of teak – the selection, propagation and preservation of elite clones. These grafted trees can be used to produce shoots for propagation by cuttings and perhaps tissue culture, and in the longer term for the production of improved seed. Research to support the rapid propagation of elite clones is recommended. Tissue culture has been applied effectively to the propagation of teak in the South-East Asian region; however, low-cost methods of plant production need to be developed in order to be able to deliver improved planting material to smallholder farmers at a price that they can afford.

Recommendation 6

Socio-economic factors impacting on smallholder decisions to plant teak, and to adopt more intensive management regimes require on-going investigation. In the past, teak planting has led to economic benefits to some farmers, but for others planting of teak may have been detrimental due to the forced sale of land to meet financial shocks to the household. Further research is recommended to better understand the complex issues underpinning agrarian systems in the northern uplands of Laos, and in order to develop appropriate extension material to support implementation of changes to current teak-growing practices. The development of appropriate teak-based agroforestry systems for smallholder farmers is essential to ensure that the large potential benefits of teak systems as distributed appropriately within upland communities.

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10.2 List of publications produced by project

Newby JC, Cramb RA, Sakanphet S and McNamara S (2012). Smallholder teak and agrarian change in northern Laos. *Small-Scale Forestry,* 11(1): 27–46.

11 Appendixes

11.1 Appendix 1: Posters Presented at Teak World Conference, 25-30 March 2013, Bangkok, Thailand.

PO-04-02

Looking beyond the woodlot: viewing smallholder teak investments from a livelihood perspective in northern Laos

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Introduction

Smallholder teak *(Tectona grandis)* plantations are seen as a valuable new component of upland farming systems in northern Laos, contributing to a transition from swidden to commercial agriculture, as well as a transition back to a forested landscape ('forest transition'). This study explores the nature of these transitions in Luang Prabang Province, where widespread planting has occurred.

Methods

1. Household surveys in 5 villages in 2009 (Figure 1)
2. Households classified according to sources of livelihood and drivers for planting teak
3. Case studies of one household for each household type. Each household interviewed in 2010 and 2012 about spatial and temporal use of land and labour and future plans.

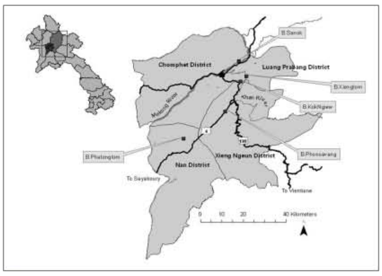

Figure 1 – Location of case-study villages

Table 1 - Profile of case-study villages

Village	Kok Ngiew	Phatong-lom	Phon-savang	Sanok	Xieng-lom
District	Luang Prabang	Nan	Xieng Ngeun	Chomphet	Luang Prabang
Village population	1,020	590	446	346	713
Main ethnic groups	Khmu Lao Hmong	Khmu	Khmu Lao	Lao Hmong	Lao
Distance to market (km)	13	60	21	14	19
Households in village	191	99	76	65	157
Households surveyed	29	25	25	21	27
Households with teak (%)	79	60	100	71	67
Average no. teak trees	1,234	749	2,106	1,550	2,185
Households with paddy land (%)	38	84	56	24 (Not planted)	56
Households with river gardens (%)	0	4	4	62	74
Households with outside employment (%)	62	4	48	29	59
Households self-sufficient in rice (%)	38	80	48	5	59
Main upland cash crop	Pineapple	Maize	Jobs tears	Sesame	Limited

Photo A – Landscape in Kok Ngiew **Photo B– Agroforestry in Phonsavang**

Results and discussion

Three of the forest transition pathways identified by Lambin and Meyfroidt (2010) were observed – an economic development pathway, a smallholder intensification pathway, and a state policy pathway. Table 2 shows characteristics of households on each pathway, outlines priorities for research and extension, and identifies constraints. The influence of government policies was felt by all households, but we only consider households to be on a state policy pathway when other drivers are absent.

Table 2 - Characteristics, opportunities, and constraints of households following different forest transition pathways

	Economic development pathway	Smallholder intensification pathway	State policy pathway
Characteristics of household livelihood system	Access to paddy land and river gardens Labour shortage for upland agricultural activities Non-farm major income sources Strategic sales of land and trees to invest in productive activities Greater ability to allow trees to meet maturity	Limited access to paddy and gardens Land shortages to allow long fallow Some off- and non-farm employment, but labour concentrated on agricultural activities Strategic and some distress sales	No paddy and limited lowland activities Land constraints Non-farm and off-farm income necessary to meet subsistence needs Distressed sales of woodlots Declining upland yields
Tree-system of interest to households	Woodlots	Agroforestry	Small woodlots and boundary plantings Other alternatives to shifting cultivation
Research and extension	Spacing, thinning regimes Pruning Improved marketing	Spacing Companion cash crops NTFP Tree genetics Marketing of trees and crops	Farm planning - "Think before you plant"
Constraints	Limited labour to manage activities remains an issue	Limited land Market uncertainty	Limited land Limited other agricultural activities Labour directed into non-farm to support consumption

Different household types are adopting various teak production systems, from woodlots to more complex agroforestry systems. Two upland fields can look identical but belong to households on very different trajectories.

- For some, the transition to teak has been driven mainly by **economic development**, making labour too scarce and costly for upland cropping.
- Other households are following a pathway driven by land scarcity and improved market access, inducing the development of **more intensive agroforestry systems**.
- Yet other households have planted teak as **a strategic move to retain land in the face of government policies**, while they look for alternative means to survive.

Integrating teak into the production system can improve the livelihoods of those households that can retain their investment for at least 10-12 years. This is more likely for households on the first two pathways.

Conclusions

Understanding these household variations is important in designing research and extension activities so they are not only directed at improving the performance of teak-based agroforestry at the plot scale, but are also compatible with household livelihood strategies.

Efforts to induce a forest transition on a regional or national scale must take account of these local variations so that a forest transition is not achieved to the detriment of rural livelihoods.

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Growth and Form of Teak in a Nelder Wheel in Luang Prabang Province, Lao PDR

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Introduction

Teak *(Tectona grandis)* woodlots are an important component of rural landscapes in the Luang Prabang province of northern Laos, and have the capacity to make significant contributions to small-holder incomes. However, a common misconception among growers has been the view that the higher the stocking density in these woodlots, the greater the returns to growers. Such a view not only increases the production time of high quality logs but also impacts on the ability of small-holders to integrate other cropping species into these woodlots. To demonstrate to small-holders the impacts of stocking rates on teak growth and form, a Nelder wheel (Nelder 1962; Parrott, Brinks and Lhotka 2012) was established at the Northern Agriculture and Forestry College at Pakxuang as part of an ACIAR funded project (FST/2004/057) in 2008.

Methods

1. Nelder wheel comprising 24 spokes and 10 concentric arcs (Figure 1).
2. Each spoke spaned an angle of 15 degrees, with a distance between each arc corresponding to the stocking rates given in Table 1.
3. Seed sourced locally and from a Myanmar provenance.
4. Site planted with stumps produced from 15 month old seedlings. Each provenance planted along alternate spokes.
5. Regular manual weed control undertaken around each tree.

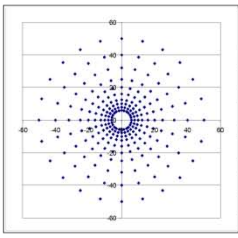

Figure 1 – **Layout of Nelder wheel (scale in metres)**

Arc (tree)	Distance from Central Pivot (m)	Area per Tree (m^2)	Stocking (sph)
1	6	Isolation	—
2	7.9	4.1	2424
3	10	6	1659
4	12.5	9.8	1026
5	16	15.7	637
6	20	23.6	423
7	25	39.2	255
8	32	62.8	159
9	40	94.5	106
10	50	Isolation	—

Table 1 – **Distance of arcs from the central pivot, area per tree and equivalent initial stocking rates (stems per hectare) in the Nelder wheel.**

Results and Discussion

Initial stocking rates in the Nelder wheels encompassed stockings commonly used in northern Laos, i.e. 1100 to 1600 stem per hectare, with a minimum of 106 sph and maximum of 2424 sph. Growth was slow in the first year. An average of 1.5, 4.2 and 7.1 m in height were recorded by the end of the second, third and fourth growing seasons respectively. While an average stem diameter of 4.3 and 8.2 cm was recorded at the end of the third and fourth growing seasons. Differences in diameter and height amongst stocking levels were highly significant (p-value less than 0.01) from end of third growing season.

Second order polynomials for height and diameter at the end of the fourth growing season, indicated strong relationships with stocking, as follows: Mean Height = 5.85 + 0.0024S − 6E-07 S^2 (R^2 = 0.99), and Mean Diameter = 7.619 + 0.002S − 8E-07 S^2 (R^2 = 0.68), where, S = stocking in stems per hectare.

Height after four growing seasons was maximized at the highest stocking rates (2,424 sph) at the centre of the Nelder wheel, while stem diameter maximized at 1026 sph, with a substantial change in the relationship of height and diameter with stocking in the third compared to the fourth growing season (Figure 2). Differences in stocking are resulting in markedly different tree form – trees at lower stocking rates had 50% larger diameter to height ratios than trees at the highest initial stocking.

Results suggest that the optimum initial tree spacing will move outwards in this Nelder wheel (i.e. to lower stocking rates) over the coming years, and that stand value is likely to maximize at intermediate stocking levels. The adoption of lower stockings rates (e.g. around 600 sph) than those currently recommended (3m × 3m, 1111sph) is likely to facilitate an initial commercial harvest (within eight to ten years) of trees exceeding 20 cm in diameter. Furthermore, initial stocking rates of around 600 sph will halve the cost of planting stock and provide greater opportunities for companion cropping with cash crops such as broom (or tiger) grass, po sa (paper mulberry), banana or pineapple.

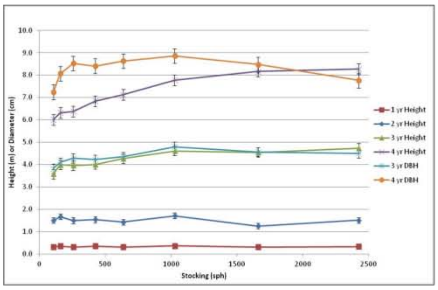

Figure 2 – **Mean height and diameter at breast height (DBH) of teak trees after each growing season, by initial stocking rate (standard errors of means indicated as vertical error bars).**

Conclusions

The successful establishment of a Nelder wheel in Laos will have a profound impact on the way teak plantings in the Luang Prabang province are established and maintained by small-holders. After four growing season, this Nelder wheel has demonstrated that a stocking rate of approximately 1100 sph or less will maximize the early diameter growth of teak in northern Laos. Reduced stocking rates are likely to allow commercial thinning at eight to ten years after planting, and permit greater incorporation of companion crops into teak-based agroforestry systems. This Nelder wheel will continue to improve understanding of optimal stocking rates for teak in northern Laos, and provide a valuable extension and teaching resource.

References

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Establishment of the Nelder Wheel August 2008. First measured early 2009

Second measurement early 2010

Third measurement early 2011

Fourth measurement early 2012

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