NURSERY TECHNOLOGY AND TREE SPECIES SELECTION FOR RESTORING FOREST BIODIVERSITY IN NORTHERN THAILAND

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ABSTRACT

The Forest Restoration Research Unit (FORRU) was established in 1994 to develop methods to restore forest ecosystems in degraded areas for the conservation of biodiversity in northern Thailand. A research programme was carried out to screen nearly 400 native forest tree species for their potential usefulness in forest restoration programmes. Studies on each species included observations of flowering and fruiting phenology and experiments on seed germination and seedling growth in the nursery. Nursery trials were essential, because very little data on seedling performance were available for most of the native species being screened. Ease of propagation was one of the key criteria used for subsequent selection of thirty "framework species" for planting trials. Larger numbers of seedlings of these framework species are now being produced for field trials. This requires more research on nursery production, planning and ultimately the drafting of "production schedules".

This paper focuses on the application of nursery technology to native tree production for a forest restoration programme. It highlights key issues related to the technology and its management for further discussion, including introduction of larger scale production to a research programme. It also emphasises the selection criteria for framework species, including the relative importance of propagation.

INTRODUCTION

Southeast Asia, in common with other tropical regions, is continuing to lose its forests and their associated biodiversity. In Thailand for example, forest cover has been reduced from about 53% in the early 1960's (BHUMIBAMON, 1986) to about 23% today (FAO, 1997). Unofficial estimates, however, put Thailand's natural forest cover at less than 20% (LEUNGARAMSRI & RAJESH, 1992). Commercial logging was banned by the government in 1989, resulting in a reduction in the rate of deforestation to approximately 0.3% per year. In recent years, this rate has started to increase again, currently to about 1% per year.

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Deforestation results from logging and agricultural expansion (HIRSCH, 1990). The increase in the rate of deforestation in recent years is indicative of continued logging, shifting cultivation and development of infrastructure. Consequently today, large areas of Thailand, including considerable parts of the extensive system of national parks and wildlife sanctuaries, comprise secondary forests subjected to differing degrees of disturbance. In northern Thailand, populations of large vertebrates have been severely depleted and many species of large birds have become extirpated from the region. As a consequence of deforestation throughout the country, biodiversity is now severely threatened.

Restoration of conservation forests

A positive development in Thailand has been the rapid increase in public awareness of the problems caused by deforestation. It is now generally accepted that further loss of forest will cause more extreme floods and droughts, damage to watersheds, loss of biodiversity and impoverishment of rural communities (ELLIOTT *ET AL.*, 1995). Complete protection of all remaining primary forest and important areas of secondary forest is unlikely, due to economic and legal constraints. Therefore, to maintain the current forested land area, or indeed to increase it, deforested areas must be converted back into forest. This need is reflected in the National Forest Policy, which stipulates that 40% of the country should be under forest cover, with 25% of the country targeted as conservation forests. This policy was implemented by designating sites of many former logging concessions as national parks or wildlife sanctuaries, which now cover approximately 13% of the country, or more than half of the total forest area (BOONTAWEE *ET AL.*, 1995). Consequently, large parts of many national parks and wildlife sanctuaries had already been degraded or deforested before they acquired protected status. If such areas are to fulfil their functions of conserving biodiversity and protecting watersheds, they must be reforested.

Within national parks and wildlife sanctuaries, where the primary objectives are conservation of wildlife and protection of watersheds, reforestation efforts should ultimately aim to restore natural forest ecosystems permanently. Rehabilitation and restoration of degraded ecosystems are extremely important components of *in situ* conservation as identified in the Convention on Biodiversity (WORLD CONSERVATION MONITORING CENTRE, 1996), but research on the biological aspects of the problem has been neglected. Large-scale restoration of forest ecosystems requires close co-operation between government agencies and local people; the development of new and technically sound methods of tree propagation and planting and the provision of resources and expertise to all participating organisations.

High biodiversity and complexity hinder attempts to recreate natural forest ecosystems in the tropics. Any individual forest type may contain several hundred tree species, each of which may have evolved intricate relationships with hundreds of other organisms, such as herbivores, pollinators and seed dispersers. Restoration of natural forest ecosystems, therefore, requires a vast amount of ecological information, of which only a small fraction is currently known. We need to understand how forests regenerate naturally, identify the factors limiting regeneration and develop effective methods to counteract them and thus accelerate regeneration (HARDWICK *ET AL.*, 1997). Planting nursery-grown seedlings is just one of several complementary options, where natural regeneration is very poor; others include cultivation and husbandry of seeds, seedlings and saplings which are already present, or prevention of fire by maintaining a network of fire breaks.

Species selection for planting

It would be difficult to implement a forest restoration programme that proposed replanting a substantial number of tree species from a complex forest ecosystem, such as the dry tropical forests of northern Thailand. Most studies to date have concentrated on more focused rehabilitation programmes which aim to catalyse vegetation recruitment, although there is still a paucity of data related to the restoration of complex tropical forests. KNOWLES & PARROTTA (1995) worked with 160 Brazilian native tree species of upland moist forest in Amazonia, and developed a species rating system relative to propagation and suitability for reforestation. Their numerical scoring system focussed on (i) seed germination, (ii) alternatives for production of planting stock and (iii) adaptability to plantation site environment and early growth rates. This was used to rank and classify 160 species evaluated in the study with respect to their suitability for planting on a rehabilitation site. Their studies demonstrated that, at a practical level, it is possible to evaluate a large number of native tree species systematically at relatively low cost. This evaluation could include fruiting phenology, seed biology, nursery practice and seedling performance following planting in the harsh environments of rehabilitation plots.

The "framework species method" of forest restoration (GOOSEM & TUCKER, 1995; LAMB *ET AL.,* 1997) was developed in Queensland, Australia in the late 1980's. It relies on the premise that early successional vegetation produced by ecological rehabilitation can be utilised by many species and provides a suitable 'framework' for rebuilding biodiversity. Essentially, native tree species are planted to "capture" the site by shading out weeds. The planted trees re-establish basic forest structure and attract wildlife by providing perches for birds and fruit as bait for seed-dispersing animals. It is this wildlife which, in its role as seed-dispersers, establishes other species in the rehabilitation areas. The principal advantages of the method are that it involves a single planting and is then self-sustaining, relying on the local gene pool to increase diversity of species and life forms. This is a great benefit in softening potentially degraded or abandoned areas to enhance the local habitat matrix and in improving overall landscape heterogeneity. In Australia, the method is very successful. For example, seven-year-old rehabilitation plots, contiguous with forest, recruited up to seventy-two plant species across all growth forms and successional phases (TUCKER & MURPHY, 1997). Seed collection, germination and the production of container-grown seedlings are all essential prerequisites of these studies on replanting.

Nursery technology available in Thailand

In Thailand, nursery technology for the propagation of woody perennial species, both by seed and cuttings, is quite advanced. However, the development of this technology has largely focused on exotic and commercial plantation trees, often associated with genetic improvement programmes. Much research has been carried out at the ASEAN Forest Tree Seed Centre, Muak Lek, where, for example, cost-effective methods for the commercial propagation of tree seedlings have been developed using coconut husk (KIJKAR, 1991a). The centre has also developed seed testing standards for commercial species such as *Dipterocarpus alatus, D. intricatus* and *Hopea odorata* (KRISHNAPILLAY, 1992) and vegetative propagation techniques for dipterocarps in general (KANTARLI, 1993). Vegetative propagation of exotic species such as eucalypts, acacias and acacia hybrids has been extensively researched, resulting for example in the production of a handbook for the propagation of *Eucalyptus camaldulensis* (KIJKAR, 1991b).

However, very little work has been carried out on the vast majority of Thailand's estimated 3,600 native forest tree species. Furthermore, the technological requirements for the nursery production of native species for forest restoration must address issues concerned with lack of knowledge, the requirement for low-tech input, maintenance of genetic diversity and handling of relatively small numbers of many different species. The requirements of this technology are clearly quite different from those of a nursery producing trees for timber or biomass, where the emphasis is on clonal propagation and seed harvested from superior trees of few species. Many of the conventional techniques developed for these species would be inappropriate for isolated small-scale 'forest conservation' nurseries and could not be directly transferred to such operations.

THE FOREST RESTORATION RESEARCH UNIT NURSERY: A CASE STUDY

The Forest Restoration Research Unit (FORRU) was established in Doi Suthep-Pui National Park (DSPNP) in northern Thailand in 1994. The unit is addressing technical problems related to the re-establishment of natural forest ecosystems on degraded sites within conservation areas (ELLIOTT *ET AL.,* 1995). FORRU's facilities include a research tree nursery, a village community tree nursery and experimental planted plots at Ban Mae Sa Mai, an Hmong hill tribe village in the north of the DSPNP. A detailed study has been carried out of tree flowering and fruiting phenology, involving some 350 species, which represent more than 50% of the tree flora of DSPNP. Descriptions, drawings and photographs were made of fruits and seedlings. An herbarium collection of dried seedling specimens was established, along with computer databases of seed, fruit and seedling morphology. Without such basic background information, it would have been impossible to make sensible choices as to which tree species to use in forest restoration projects. Key elements of FORRU's research programme related to the selection and propagation of tree species for forest restoration, including: (i) screening a large number of tree species for their ease of propagation from seed; (ii) identifying species suitable for planting to complement natural seedling establishment (so-called "framework species") and (iii) developing appropriate methods to propagate such framework tree species.

Seed germination studies

Early on in FORRU's propagation programme, a strategic decision was made to carry out a preliminary screening as many of the native tree species as possible, rather than to attempt to select a small number of species initially for more detailed study (ELLIOTT *ET AL.*, 1995). Consequently, seed germination experiments were initially designed to identify tree species that germinated easily without any special treatments. Seeds were removed from fruits and planted in modular plastic trays under two shade treatments: partial shade (40% of full sunlight, similar to the quantity of light in partially regenerating gaps) and deep shade (less than 1% full sunlight, similar to the quantity of light under an evergreen forest canopy). For the partial shade treatment, seed trays were placed on top of concrete benches, under a transparent plastic roof, whilst for the deep shade treatment, trays were placed underneath the same benches, which were screened around the sides with black plastic shade netting. For each of the two shade treatments, 72 seeds were divided into three replicate batches of 24, which were randomly assigned to different benches and watered daily. Each replicate consisted of 24 adjacent modules (3.5 x 3 x 7cm) in one seed tray, containing a forest soil-based compost, mixed with coarse sand to improve its structure. Where possible, germination experiments were repeated in subsequent years. Germination trials were checked every few days, and the dates of the first, median and last seed to germinate were recorded.

Ease of nursery propagation is one of the key criteria for selection of framework species. Consequently, data on propagation were important in drafting a provisional list of framework species. When the list was first drafted in May 1997, germination trials had been carried out with approximately 350 species. These data demonstrated that approximately 50% achieved a germination rate of 50% or more in one or both shade treatments (unpublished data). Some 29% germinated significantly better in partial shade, whilst only 2% germinated significantly better in deep shade (paired t-test, $p \leq 0.05$). The remainder showed no significant difference in germination between treatments.

Selection criteria for framework species

Based on the "framework species method" described by GOOSEM & TUCKER (1995) and LAMB *ET AL*., (1997), a series of criteria were compiled which we believed would be important for the selection of framework species in the seasonally dry tropical forests of northern Thailand. These were:

- ease of propagation in the nursery
- seedling survival in the rehabilitation plots
- seedling growth rate in the rehabilitation plots
- crown architecture and the ability to shade out weeds in the rehabilitation plots
- ease of natural dispersal
- attractiveness to frugivores
- age of fruiting
- rarity

In May 1997, we screened all of FORRU's databases and anecdotal information to produce a provisional list of framework species. At that time, not all of the relevant data were available for many of the species. Members of the Moraceae (figs), Leguminosae and

Fagaceae (oaks and chestnuts) are prominent amongst these species. The candidate framework species have been described elsewhere (ELLIOTT *ET AL*., 1998).

Germination of framework species

Propagation data are presented for a selection of the framework species from the germination trial in partial shade, all of which have been considered as candidates for framework species (Table 1).

Table 1. Seed germination of selected framework species in partial shade

Framework species	Month of seed collection	Season of dispersal	Mean % Germination (SD)	Germination of median seed (days)
Schima wallichii	Mar	Late dry	54.2 (8.3)	12
Erythrina subumbrans	Apr	Late dry	38.9 (2.4)	7
Castanopsis diversifolia	Sept	Late rainy	45.8 (25.0)	221
Glochidion kerrii	Oct	Early dry	38.9 (4.8)	134
Diospyros glandulosa	Dec	Early dry	77.8 (6.4)	69
Manglietia garrettii	Oct	Early dry	73.6 (4.8)	81

Data have not been presented for germination in deep shade, as in none of the framework species was this significantly higher than that obtained in partial shade. In view of this observation, these species should not be germinated in deep shade, due to an increased risk of seedling mortality caused by higher incidence of pests and diseases. Whilst most species had germination percentages in partial shade well in excess of 50%, there were several exceptions. However, several such exceptions had other characteristics that outweighed any disadvantage of a lower germination percentage. An example of this category was *Erythrina subumbrans*, which scores highly for the other characteristics of framework species, but has a germination percentage of 39% in partial shade, and 28% in deep shade[4]. Not all of the candidate framework species identified however scored highly in all other categories. Therefore, the list is continually modified as new data become available.

The production schedule: a nursery management tool

Following initial selection of framework species, it was necessary to scale up seedling production, not only to understand how to manage nursery production, but also to test the suitability of the selected potential framework species for planting out in degraded sites. For the latter, large numbers of seedlings were required. This required changes in FORRU's research nursery, from one dealing primarily with large numbers of species being germinated in small replicated trials, to a nursery capable of managing the production of large numbers of seedlings of a smaller number of species.

[4] Editor's note: as this paper went to press, additional germination trials achieved rates of up to 63% over 21 days for this species (WOODS, unpublished data).

Consequently, FORRU is in a position to advise other nurseries, whether they are attached to schools, villagers or national parks, not only how to propagate tree seedlings but also how to manage production on whatever scale might be required.

Seasonal dormancy is common in some semi-deciduous forests (GARWOOD, 1983) and will inevitably affect nursery operations. FORRU has a data set for some 350 species, which is being analysed to study seed germination at the community level (manuscript in preparation). However, a simple analysis of the phenology and germination data for the framework species as a group is extremely useful for nursery managers responsible for producing large numbers of seedlings of perhaps 30-50 framework species. Compilation of a production schedule is needed to plan space and labour requirements throughout the year. Without such a nursery management tool, it is very difficult to produce seedlings of an acceptable quality, when they are required for planting.

Data on dormancy and germination were used to help formulate a production schedule. NG (1978, 1980), in a similar study of Malaysian tropical rainforest tree species, used the first and last day of germination of each species to categorise them into one of three groups; rapid (all seeds germinate within 12 weeks), delayed (all seeds germinate in 12 weeks or more) and intermediate. This apparently arbitrary division was actually related to forest management and the period of time defined by Ng as rapid germination was just sufficient to include all species of the Dipterocarpaceae. Of 200 species examined, 65% fitted into the rapid category. Therefore, in the tropics, soil seed banks have a relatively short viability and cannot contribute much to the restoration of forest to sites that have been severely degraded over a long time. More recently, GARWOOD (1983) published an elegant study of seed germination in a seasonal tropical forest in Panama. Whilst she assessed her community data using the categories proposed by NG (1980), her primary analysis related to the identification of three germination syndromes based on the season of seed dispersal and the mean length of dormancy: delayed-rainy, intermediate-dry and rapid-rainy.

In the present study, we noted the time to germination of the first, median and last seed. If the median germination time is compared with the time of seed dispersal, a very interesting pattern emerges. In almost every month there are some framework species which, have a relatively short dormancy period within the nursery environment. However, the seeds of species dispersed towards the end of the dry season or start of the wet season tend to germinate relatively quickly under nursery conditions (e.g. *Erythrina subumbrans* and *Schima wallichii*). Seeds of species dispersed towards the end of the rainy season or start of the dry season are more likely to have a much longer period of dormancy (e.g. *Glochidion kerrii* and *Castanopsis diversifolia*), although there are exceptions, such as *Manglietia garrettii* and *Diospyros glandulosa*. Based on this single group of framework species, there is a clear indication that germination syndromes, similar to those reported by GARWOOD (1983), exist. This begs the question: ‘Is this a problem that should concern the nursery manager?’

In the monsoon climate of northern Thailand, container-grown seedlings are planted out in the restoration plots only at one time of year, the start of the rainy season. The nursery manager is faced with the challenge of producing a crop of seedlings of some 30-50 native tree species, all to be dispatched at the same time of year. This production exercise is made very difficult by seasonal variation in seed dispersal, dormancy/germination and growth rates amongst the framework species. A provisional production schedule was produced for all of the framework species and an example is illustrated in Table 2 (see also FORRU, 2000). The production schedule contains all the basic information, which nursery managers need to plan activities throughout the year, including time of seed collection, germination period, and hence pricking out time, and dispatch time.

Variability amongst framework species means that nursery managers may need to exert some control over growth rates, to produce crops of tree seedlings of particular species that reach the ideal size for planting at the right time of year. Re-examining some of the examples above; *Erythrina subumbrans* is ideal for nursery production in this context, because, following seed collection early in the year, it germinates rapidly (median germination time of 10 days). After pricking out, it reaches the required size for hardening and planting out in time for the start of the subsequent rainy season in June.

In contrast, *Prunus cerasoides* produces seed in March-May, providing insufficient time to produce a plantable tree before the June planting date. However, *P. cerasoides* seeds germinate relatively quickly[5] and its seedlings grow rapidly in containers. Therefore, seedlings are ready for planting by November-December, 6 months ahead of the planting season. Consequently, nursery managers have three options: i) to hold the plants in the nursery until dispatch time, which wastes time and space; ii) to store seeds and sow them at an appropriate time nearer to the dispatch date or iii) to sow seeds in a sterile (zero nutrient) mix. In the latter case, seedlings can be held in the tray, for up to 12 months before pricking out. Although we are not aware of *P. cerasoides* seed being stored for any length of time in Thailand, there are reports that it can be dried and stored for up to 6 months.

Other species are more problematic. For example, *Glochidion kerrii* seed usually ripens late in the year, which should allow more time between sowing and dispatch than is available for *E. subumbrans* or *P. cerasoides*. However, as species dispersed in the late rainy/early dry season, germination is much slower under nursery conditions (median germination time of 134 days) and the growth rate of the seedlings in containers is also relatively slow. Therefore, seedlings will not be ready for planting at the start of the following rainy season. This means that after pricking out, they may be kept in the nursery in containers for more than 15 months.

Table 2. A provisional production schedule for three framework species

Species	Month																										
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Erythrina subumbrans				S	S C	S C	S C		H	P						S	S	S C	S C		P						
Prunus cerasoides						S	S	S C	C	C										H	P						
Glochidion kerrii	S	S	S C	C	C	C														H	P						

S-seed sowing; C-pricking out into containers; H-hardening; P-planting

[5] Editor's note: recent results show that germination can be considerably accelerated by gently cracking open the pyrenes in a vice or with a hammer and completely removing the tough endocarp that surrounds the seed (WOODS, unpublished data).

Nursery production of high quality seedlings; knowledge and expertise

The production schedule described above allows the nursery manager at FORRU to plan all activities in the nursery to produce high quality seedlings, which are strong, healthy and able to withstand the stress of transplantation into degraded sites. This, of course, is based on current knowledge. For some species, we are close to the optimum production schedule, for others, more research is required to improve the efficiency and quality of production. The combination of seasonal patterns of germination and dormancy, variable growth rates between species and the narrow window for planting can create complex problems for nursery management. The next logical step is to review nursery practices applied to individual framework species and identify areas that may require further research. This process involves appraisal of nursery research requirements. It should be carried out for any nursery operation that is part of a forest restoration programme.

Some nursery practices have been extensively documented elsewhere and can be considered as 'standard', for example:

- grading and quality control
- pest and disease identification and control
- potting
- compost
- watering
- weed control

Whilst these factors deserve careful consideration in any nursery operation, they do not require a major research effort. In contrast, other aspects relating to nursery production of native tree species are not well understood and should be carefully considered in any nursery research programme. The identification of parent trees to supply seed and the implications for genetic diversity are particularly important in forest restoration projects for the conservation of biodiversity and are poorly understood, but are outside the scope of this paper[6]. Other key aspects, directly relating to nursery production, that require further consideration are discussed below.

Fertiliser application

The compost used in small-scale container nurseries varies considerably and usually depends on raw materials that are available locally and cheaply. The main bulk ingredient is often local forest soil, which will be highly variable both in its structural attributes, such as 'available water holding capacity' and 'air filled porosity', and its pH and nutritional qualities. It may also contain feral earth and flat worms, antagonistic fungal and bacterial species, as well as weed propagules. Coarse amendments are usually added to the bulk

[6] Editor's note: however, this topic did receive considerable attention during discussion sessions; see Part 7 proposal 4.2.

ingredient, such as sand, rice or coconut husks, to improve the structure of the compost. Whatever the final compost mix, seedlings of most native tree species may still require the application of nitrogen, phosphorus and potassium, even where forest soil constitutes the bulk ingredient. This is especially true of soil-less mixes. Application of the total fertiliser requirement as soluble fertiliser at the time of pricking out could damage seedlings and later lead to nutrient deficiencies due to leaching. In practice, these nutrients are supplied at regular intervals, either as a dilute soluble feed, or in a controlled release form (CRF, e.g. Osmocote). When applying CRF, the nursery manager may intend to influence plant quality, or actual growth rates, as discussed earlier with the production schedule, of many different species with different requirements. However, there will be a choice of several formulations, designed to last for different periods of time, typically 3 to 19 months. The rate of release, which is dependent on temperature, and the distribution of the granules within the relatively small volume of the container will need to be measured according to the manufacturers recommendation.

An alternative strategy that may offer more potential for manipulating framework species on an individual basis is liquid feeding. Using this method, it should be possible to more precisely control amounts of nutrient applied and vary applications to suit different growth rates. However, such an approach requires skilful application and the performance of the seedlings must be continually and closely monitored.

Manipulation of root growth

In temperate forestry nurseries, the ratio between root and shoot dry mass is widely used as an index of plant quality. Seedlings with large, healthy fibrous root systems are better able to supply shoots with water. A high fibrous root:shoot ratio enables seedlings to withstand periods of drought stress after planting. This could be especially important in the manipulation of growth of tropical seedlings, prior to planting in the harsh environments of degraded sites. Large, woody roots are likely to offer the best direct resistance to desiccation, but must themselves have a good network of young, fine roots in order to take up further water from the soil. The period needed to develop an efficient root system needs to be known, to allow sufficient time for root development following final manipulation of root form prior to hardening and planting. This applies particularly to open ground seedlings, but also to some extent to container-grown seedlings. It is also known that temperate tree species differ in their abilities to i) withstand damage to their 'nursery' root system during transplantation and ii) regenerate new roots after transplantation. This might also be true for Thai framework species, but very little is known. Clearly, it is important for nursery managers to have this basic understanding of the functional morphology of root systems and factors affecting it.

Manipulation of shoot growth

Shoot pruning is rarely practised, usually when plants require holding back in the nursery. Its effects are not known for most Thai framework species. For species with strong apical dominance, removing the leading shoot might not affect final form. For other species, removing the leader might stimulate axillary bud break and a more densely branching crown; a desirable trait for shading out weeds on degraded sites.

Containers

An absence of root spiralling and other root deformities is an essential requirement of container-grown plants. Root morphology is strongly influenced by container design. Most seedlings produced in small nurseries are grown in black polythene bags. Whilst such bags are basically acceptable, better rigid containers are available, which produce better root form. Ridges or grooves are basic design features of such containers. They direct root growth downwards and prevent spiralling. Such containers work best with air-pruning, but the combination of more expensive containers, with a raised standing down area may not be feasible for low-budget nurseries. The volume of containers needed to accommodate species with different growth rates and propagule sizes is another important consideration.

Alternative propagation methods

Trees are not only raised directly from seed. Many nurseries obtain material as natural seedlings (wildlings) transplanted from elsewhere, and others use vegetative propagation, particularly for economically important species. Difficulties with clonal propagation relate to the loss of rooting ability with maturity of woody perennial species. This requires root-inducing treatments such as auxin application, and pruning to stimulate young, vigorous shoots, e.g. stooling and hedging. Key questions for nursery managers relate to clonal propagation. Is planting clonal material useful, in terms of uniformity? If so, how many different genotypes would be considered suitable for propagation? How much effort would be needed to develop an efficient propagation system?

It is unlikely in nurseries, where some 50 framework species are being produced, that all these variables could be optimised for every tree species. Even if the resources were available, it would lead to unmanageable production schedules. All factors are important and should be carefully considered for the 'framework tree crop' as a whole. However, researchers should give more attention to individual species that are problematic, in terms of timing of seed availability, dormancy and growth rates in containers.

Seed storage

Short-term seed storage of up to a year would be a useful tool, both for managing the nursery production schedule of species such as *Prunus cerasoides* (as described earlier) and for transporting seeds to nurseries where local seed is unavailable due to forest clearance. In other cases, it may be desirable to store seed for several years when a species' fruit production follows a 'masting' pattern, i.e. fruit is only produced at intervals of several years (JANZEN, 1978). For such species, seed will be abundantly available one year, far exceeding the nursery's capacity to utilise it all, but will be scarce or unavailable in the following years. It would clearly be useful to be able to store such seed and stagger the production of seedlings over several years until the following masting year.

Successful storage must maintain viability, whilst preventing germination. This is usually achieved by drying seeds to a low moisture content and/or cooling to about 4°C (KRISHNAPILLAY *ET AL*., 1993). Seeds that are tolerant of drying and cooling are classed as 'orthodox' and are easiest to store. Unfortunately, many tropical forest species have 'recalcitrant' seeds that do not tolerate desiccation or low-temperature storage. Recent research suggests the existence of a third, 'intermediate' category. Such seeds can be dried but not cooled, and quickly deteriorate in storage (KRISHNAPILLAY *ET AL*., 1993). The long-term storage of recalcitrant seeds is a difficult problem, which remains unsolved despite attracting considerable amounts of research funding. An important first step is to identify species, which can tolerate storage and this is still not known for the majority of forest tree species in south-east Asia. In the case of FORRU for example, this might involve experiments with a small number of framework species such as *P. cerasoides*, whose production would immediately benefit from short-term storage.

Concluding remarks

This paper has focused on FORRU's application of nursery technology to native tree production, to demonstrate a successful and continuing research programme. It has summarised the selection criteria for framework species and described issues relating to their propagation. The final section of this paper aims to stimulate discussion on those areas of nursery production technology for native tree species that are not well understood and should be carefully considered in future forest restoration programmes.

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COMMENT

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One of the main concerns of FORGENMAP is seed supply. We must supply quality seed; we need genetic diversity; seeds must match between the site of origin, and the planting site; the seed source needs to be well documented. Further, the seed source needs to be from a broad genetic base, this is important. The seedlings must also be flexible and well adapted. Biodiversity is not important for FORGENMAP but it is clearly embraced at FORRU. The use of framework species is a very good shortcut to forest restoration. One thing that has not been mentioned is that these framework species are specific to certain forest types. For example, we can not use highland species for lowland therefor we need more research in this area[7].

[7] Editor's note: this topic stimulated much discussion and was subsequently proposed as a research priority; see Part 7, proposal 4.1.