# *An overview of the conservation status of potential plantation and restoration species in Southeast Asia*

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## *Abstract*

The genetic resources of many Southeast Asian forest tree species are endangered. This includes most of the region's commercially valuable tree species and genepools but also species that would contain many useful traits if properly tested. While techniques for forest plantations, restoration and rehabilitation have been successfully developed, the genepools to source quality genetic material for such projects are fast disappearing and the options for future benefits are diminishing. This article summarizes the current status of efforts made for the conservation of potentially useful plantation and restoration tree species in Southeast Asia.

*In situ* and *ex situ* conservation of trees in living stands is the most common strategies for conservation of forest genetic resources (FGR) in the region. *Ex situ* conservation through storage has not been widely applied, mainly due to the recalcitrant nature of most tropical rainforest tree seeds. *In vitro* slow growth conservation and cryopreservation of certain species groups are studied as a future measure to complement the conservation of living stands; however, implementation of these strategies is still very limited.

Despite improvements in national legal and policy framework for conservation, such as development of national strategies for FGR conservation in certain countries, the implementation of co-ordinated conservation programmes for valuable and potentially useful tree species calls for an increase in resources for operationalization as well as some regional collaboration.



**Key Words**: Forest genetic resources, *in situ* and *ex situ* conservation, tree breeding, conservation strategy, gene-ecological zonation

## *An overview of the conservation status of potential plantation and restoration species in Southeast Asia*

## *Introduction*

According to FAO (2001a), there are some 20 million ha of plantation forests in Southeast Asia (Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand and Vietnam), including rubberwood plantations, but excluding oil palm and coconut plantations. The plantation forest area is fast increasing in many countries as a result of major government-controlled reforestation efforts. For example, in Indonesia, the Government initiated a reforestation programme promoting the establishment of industrial forest plantations, covering 6.2 mill ha. An annual planting target of 400 000 ha has been set (Suseno 2001). In the Lower Mekong Countries of Vietnam, Laos, Cambodia and Thailand there are an estimated 21 million hectares of bare land, much of which is suitable for rehabilitation.

However, only a small portion of potentially useful tree species is managed by humans in tree planting programmes. Jansen *et al*. (1991) have calculated that close to 1500 tree species have – or have had economic importance as timber in Southeast Asia (Table 1). However, as a contrast, the mainly exotic genera *Acacia*, *Eucalyptus, Gmelina, Hevea*, *Tectona*, *Casuarina*, *Pinus* and *Swietenia* cover more than 75% of the plantation forest area in the region (FAO 2001a). The number of species tested for suitability in reforestation efforts is slowly increasing, but most afforestation and reforestation projects in the region still include very limited number of species.

Table 1. Selected economic uses of Southeast Asian tropical rain forest plants (source: Jansen *et al*. 1991)

| **Product/commodity group** | **Species (number)** |
|---|---|
| Timber trees | 1462 |
| Medicinal plants | 1135 |
| Ornamental plants | 520 |
| Edible fruits and nuts | 389 |
| Fibres | 227 |
| Rattans | 170 |
| Poisonous and insecticidal plants | 147 |
| Spices and condiments | 110 |
| Others | 1790 |
| **Total** | **5950** |

While many techniques for forest restoration and rehabilitation have been successfully developed and tested, the genepools from which to source local genetic material for planting and restoration projects are fast disappearing and the choices for future are diminishing. The genetic resources of many Southeast Asian forest species, in particular tree species are highly threatened; this includes species and genepools of proven and potential useful traits.

## *The importance of genetic diversity in trees*

Genetic diversity within species is important for the short-term ecological natural adaptation and long-term survival and evolutionary change of any species (e.g. Falk & Holsinger 1991; Hamrick 1993). It has been suggested that trees perhaps are genetically more variable than any other known group of species (e.g. Hamrick & Godt 1990; Libby 1987). Tropical trees are generally highly heterozygous, with mechanisms to maintain high levels of intraspecific genetic variation, such as high rates of outcrossing and the dispersal of pollen and seeds over wide areas (e.g. Hamrick 1993; FAO, FLD, IPGRI 2004a). However, reduced population size or impaired gene flow can lead to increased inbreeding and, as a result, in reduced heterozygosity. Decreased genetic diversity and increased homozygosity may affect population viability, adaptation and growth rates (e.g. Vrijenhoek 1994; Kjaer 1997). Therefore, genetic erosion is detrimental to the short-term viability and evolutionary potential of individuals, populations and species as well as to the human use of genetic resources (Brown *et al*. 1997).

Genetic diversity also contributes to the resistance of a species against pest and diseases as well as their resilience in the case of climate change. Examples from agriculture show the potential of within-species genetic variation. For example, rice cultivation systems that make use of more than one variety can be at the same time more productive and more resilient to pests than genetically uniform systems (e.g. Wolfe 2000; Youyong Zhu *et al* 2000).

In the whole Southeast Asia, less than 100 tree species are or have been included in tests or breeding programmes to assess their suitability for use in e.g. plantation programmes. Even less tree species have been evaluated for land rehabilitation. It is clear that the potential of indigenous tree species and their genetic diversity is not yet fully utilized. As forest resources, species and distinct populations are disappearing, many potentially useful genepools are being lost.

A State of the Art Report on the Research on Forest Tree Genetic Diversity prepared for the XXI IUFRO World Congress in 2000 concluded that, in general, the state of scientific knowledge on the importance of forest genetic resources (FGR) in various research areas and in particular in forest management, was far from satisfactory. Reliable inventory information to species or population level is not available, except for a few showcase species. For example, tree species distribution maps are generally developed or updated nationally, often with very little resources, and with no regional collaboration in methodology. FAO is working towards the development of a global FGR assessment within the next five to ten years (Sigaud 2005, unpublished).

## *Threats to species and genetic diversity*

S.E. Asia is experiencing a rapid loss in forest cover. For example, the annual deforestation rate in Indonesia been estimated by Harsono (2000) to be up to 1.46 million ha. Very few large, ecologically intact, and undisturbed natural forests, also called 'frontier forests' by the definition of the World Resources Institute remain in Southeast Asia; most of Asia's remaining frontier forest is confined to the islands of Borneo, Sumatra, Sulawesi, and Irian Jaya (Bryant *et al*. 1997). Table 2 displays the perceived threats to forest genetic diversity (tree species in particular) in Southeast Asian nations.

Table 2. Threats to forest genetic resources as perceived by national experts

| Country | Major present threats to FGR | Source |
|---|---|---|
| **Cambodia** | Encroachment and shifting cultivation at former concession sites; unsustainable harvests at concessions | So Thea (2004) |
| **Indonesia** | Illegal logging and illegal trade of timber; forest fires | Masripatin *et al*. (2004) |
| **Lao PDR** | Encroachment into forest for permanent or slash-and-burn agriculture; forest fires; logging; infrastructure development | Phongoudome and Mounlamai (2004) |
| **Malaysia** | Plantation and infrastructure development | Lee & Krishnapillay (2004) |
| **Myanmar** | Illegal logging, shifting cultivation, etc. | Thaung Naing Oo (2004, unpublished) |
| **Philippines** | Land hunger | Razal *et al*. (2004) |
| **Thailand** | Illegal logging (high wood prices) | Sumantakul (2004) |
| **Vietnam** | Shifting cultivation; inappropriate harvesting practices | Nguyen (2004) |

One of the greatest threats to the FGR in the region is an inappropriate pattern of forest fires. Expert estimates identify that globally, altered fire regimes affect an estimated 84% of the area of ecoregions recognized as being critical to biodiversity conservation. Human-induced global warming and changing patterns of rainfall and drought already influence fire patterns in many parts of the world. The tropical moist broadleaf forests of Southeast Asia are largely sensitive to fire (The Nature Conservancy 2004). Illegal and unsustainable logging, as well as conversion of forestland for agriculture and development are other threats to forest genetic resources. Tree populations in fragmented landscapes are at high risk due to environmental changes, demographic stochasticity and reduced genetic diversity (e.g. Meffe & Carroll 1997). The local market value of certain species (such as agarwood-producing trees or certain timber species) can be very high, which makes possible total exhaustion of the natural resource.

## *Institutional setting and national programmes for FGR conservation*

The national legal and policy framework for forest conservation has developed rapidly since the UNCED in Rio 1992; many countries have revised their forest legislation and policies to better incorporate forest conservation. Considerations related to forest genetic resources have been integrated within sectoral or thematic frameworks, such as national forest programmes and biodiversity action plans. The preamble of the Convention on Biological Diversity (CBD), adopted in 1992, affirms that states have sovereign rights over their biological and genetic resources, and that they are responsible for conserving their biological diversity and for using their biological resources in a sustainable manner (UNCED 1992). In June 2004, the CBD adopted an expanded work programme on forest biological diversity. This programme makes specific reference to forest genetic resources and integration of related concerns both in the conservation of biological diversity and in sustainable forest management, making it the most comprehensive legally binding international instrument to cover technical, regulatory and property-related aspects of forest genetic resources (Sigaud *et al*. 2004). An analysis of links between the CBD programme on forest biological diversity and other international forest-related instruments and activities is found in FAO (2003).

So far, national strategies specifically for the conservation of FGR have been developed in Thailand and Cambodia (FORGENMAP 2002; FA/CTSP 2003a). Similar development is in progress in Lao PDR, Indonesia and Vietnam. However, so far funds are lacking for implementation of these strategies. Most countries in the region have created national priority tree/forest species lists, often through a participatory process. National workshops for priority species selection involving multiple stakeholders were organized in Cambodia, Indonesia, Lao PDR, Vietnam and Thailand as a part of the Danida-funded national tree seed projects.

The development of the Global Strategy for Plant Conservation, which was agreed upon at the 6th Conference of Parties to the CBD, calls for the countries to develop a National Strategy for Plant Conservation with ambitious and concrete targets for *in situ* and *ex situ* conservation of their indigenous flora (for more information, see the CBD website at http://www.biodiv.org/programmes/cross-cutting/plant/default.asp) Up to date, at least Malaysia has organized the first meeting to initiate the development of a National Strategy for Plant Conservation. Many other national and international biodiversity conservation projects are ongoing in the region. In many cases national FGR conservation is guided or supported by commitments made at the international level and frequently rely on international or private funds (Sigaud *et al*. 2004).

In general, conservation of forest biodiversity, especially at the level of genetic diversity, is a task of the government agencies, such as forest departments and forest research institutions. Successful long-term conservation of plants requires financial commitment over long time periods, which can seldom be guaranteed – even less by small institutions. In addition, a few regional programmes and projects have focused on FGR. Non-governmental organizations have so far played a minor role in conservation of FGR. However, the efforts of local people and communities in conservation cannot be underestimated. As an example, in Indonesia, more than 100 agencies, groups and individuals active in FGR conservation have been identified (Masripatin, pers. comm.). A recent summary of the national and regional status of FGR conservation and management in Southeast Asia is provided by Krishnapillay (2002), Koskela *et al*. (2002) and Luoma-aho *et al*. (2004); available for download at www.apforgen.org.

The institutional development in Vietnam is an example that started already before the 1992 UNCED conference. Recognizing the importance of native species and varieties in development, the Ministry of Science, Technology and Environment (MOSTE, presently the Ministry of Science and Technology - MOST) issued in 1987 the first Regulation on Management and Conservation of Plant, Animal and Micro-organism Genetic Resources. The second, official regulation issued in 1997 emphasized the priority of conserving native, precious and rare genetic resources, which can be assessed and used in future for serving economic development of the country. Since 1989, continuous funding has been given for research projects relating to genetic resources including conservation and management of agricultural crops and FGR. The Forest Science Institute of Vietnam (FSIV) has been appointed as the focal institute for research on FGR conservation and management in Vietnam.

## *Methods and tools for conservation of genetic resources*

The aims of genetic management are to safeguard the evolutionary potential of ecosystems and species, and to ensure the enhancement and sustainable utilization of the genetic variation available to meet present and future human needs (FAO 2001b).

The basic concepts in conservation of genetic resources have their origins in the conservation of genetic resources in agricultural plants. Conservation of the genetic resources of agricultural plants is quite clearly oriented by species, whereas the term "forest genetic resources" often includes the genetic resources of all component species in an ecosystem, and, as a result their conservation goes beyond the scope of single species (Finkeldey 1996).

Successful long-term conservation of genetic diversity of species of natural ecosystems requires a good understanding of the ecological interactions between species and ideally begins with the surveying and inventorying of existing resources. Moreover, as a contrast to crops, trees are long-living organisms and start reproducing only at an old age. As stated by Palmberg-Lerche (1994), it is possible to conserve an ecosystem and still lose specific species, or to conserve a species and lose genetically distinct populations, genes or gene complexes that may be of future value. Therefore, it is important to specify clearly the level or levels targeted for conservation as well as the objectives of conservation. Ziehe *et al*. (1989) have suggested that the basic objectives of conservation of genetic resources are the preservation of particular traits, unrecognized variation and adaptability.

Many helpful practical guidelines for the conservation of forest genetic resources have been developed e.g. by ITTO and RCFM (2000a,b,c,d) for Southeast Asia in particular and Kjaer *et al*. (2001), Theilade (2003) and Theilade & Petri (2003) for *ex situ* conservation of tropical trees in general. FAO, DFSC, IPGRI (2001) and FAO, FLD, IPGRI (2005) provide a recent general introduction to *in situ* and *ex situ* conservation of forest genetic resources. Drysdale *et al*. (1994) and Thielges *et al*. (2001) provide a good set of technical papers on conservation of commercial tropical trees, with main reference to Southeast Asia.

FAO has also been active in developing guidelines for FGR conservation (see e.g. FAO 1984; FAO 1993a; FAO 1993b). Maxted *et al*. (1997) have compiled general guidelines for *in situ* conservation of plant genetic resources and Hawkes *et al*. (2000) for *ex situ* conservation. A comprehensive textbook on forest conservation genetics has been edited by Young *et al*. (2000). Sutherland *et al*. (2002) developed guidelines for addressing tree seed health for germplasm conservation. The Danida Forest Seed Centre (DFSC) - now merged with Forest & Landscape, Denmark (FLD) has developed many practical guidelines for collecting and handling of reproductive material for many species and also published case studies on FGR conservation that are freely available from the website of FLD (see www.dfsc.dk). Thomson (1995) has provided guidelines for the collecting of woody perennials for conservation purposes. Research on handling and storage of intermediate/recalcitrant tropical forest tree seeds has been carried out by many national institutes as well as jointly by DFSC, IPGRI and FAO (Sacande *et al*. 2004). Graudal *et al*. (1997) have drafted guidelines for planning national programmes for conservation of FGR. Past projects such as FAO's regional Forest Tree Improvement Project (FORTIP), Forest Genetic Resources Conservation and Management Programme (FORGENMAP) in Thailand, and Indochina Forest Seed Programme (ITSP) have also developed useful guidelines on forest tree improvement, e.g. selection of plus trees, propagation methods, establishment and management of seed orchards, seed stands, as well as conservation, utilization and management of FGR; however, some of these are not easily available.

Specific strategies and action plans for conservation of individual species or species groups are being developed, using a diversity of approaches. Development of a conservation plan for genetic resources of *Pinus merkusii* in Thailand is an example of such species approach (Theilade 2000). The information necessary for a creating a sound genetic conservation strategy includes distribution maps and assessment of the genetic diversity within a species. For most species, data on genetic variation is at best minimal and information has to be estimated based on habitat distribution (gene-ecological approach).

Molecular genetic tools have been applied to quantify the spatial patterns in genetic diversity within and between populations of certain species, which is valuable in the prioritization and strategic planning of conservation efforts (e.g. Namkoong and Koshy 2001; Changtragoon 2004). It is also possible to identify populations containing rare or even unique alleles. Nevertheless, for the vast majority of endangered forest species, no detailed conservation plans or strategies have been developed or implemented; sadly this is the case for numerous of the most economically important and useful species of S.E: Asia.

Finally, regular monitoring of the status of *in situ* and *ex situ*-conserved populations in remote areas may be a time and money consuming effort. For example, the latest comprehensive inventory of plant genetic resources in Peninsular Malaysia was carried out in the early 1990s (Saw & Raja Barisan 1991). In addition, the information about conservation stands and projects has to be maintained over a very long period of time, which can be a challenge (Suseno 2001; Theilade 2003).

## *In situ* conservation

*In situ* conservation means the conservation of genetic resources in their natural habitat (e.g. UNCED 1992). The large majority of forest species and genetic diversity within is still conserved in natural and semi-natural ecosystems in and outside protected areas. Considerable progress has been made in the establishment of protected areas during the past decades; the number of protected areas globally has tripled over the past 20 years. According to the 2003 United Nations List of Protected Areas there are 2656 protected areas in Southeast Asia, covering an area of 759 788 km2, i.e. 14.8% of the land area (Chape *et al*. 2003). However, the growth in protected area systems has not yet halted or remarkably slowed down the decline in the global biodiversity and species loss. Moreover, according to IUCN (1999), only 12% of the world's endangered tree species are recorded in protected areas and 8% are known to be in cultivation (for more information, see the website of UNEP World Conservation Monitoring Centre at www.unep-wcmc.org). Unfortunately, protected areas are not always adequate for protecting the resources of highly commercially valuable species due to encroachment, illegal logging and timber poaching in conservation areas (Subiakto *et al* 2001; WWF 2004). Often the most valuable forest genepools are the most critically threatened. In the cases where protected areas or conservation stands alone do not sufficiently conserve the genetic diversity within tree species, establishment of an *ex situ* gene conservation programme will be necessary as a "complementary" approach.

Identified seed sources and seed stands are commonly considered as *in situ* protected sites, fulfilling two objectives simultaneously; i.e. seed production and conservation of genetic resources (e.g. So Thea 2004; Lee & Krishnapillay 2004). Thus, work is underway to include the location of Cambodian protected seed sources into the national protected area system as IUCN Category IV sites, which are defined as "Habitat or Species Management Areas" (Sloth, pers. comm.).

In Cambodia, conservation of FGR for seed production is implemented using gene-ecological zonation (FA/CTSP 2003c). Several indigenous tree species are endangered or vulnerable and many distinct populations are threatened with extinction. In response, the Forestry Administration (FA), with the Cambodia Tree Seed Project (CTSP) developed a national Forest Gene Conservation Strategy to conserve the genetic diversity of useful and economically important tree species (FA/CTSP 2003a). Identification of priority tree species for conservation was based on their socio-economic importance and conservation status. Field surveys were carried out and distribution maps of priority species produced. The level of threat was assessed according to IUCN categories. Ten ecological zones were defined based on rainfall regimen, temperature, dry – period, vegetation, and soils. The model was used to estimate patterns of genetic variation within species assuming that similarities of ecological conditions imply similarities of genetic constitution (Graudal *et al*. 1997). All data is digitized and cross-referenced within a dbase with multi-query software. Gene-ecological zoning is a practical and cost-effective tool for gene conservation, as well as species-site matching and seed distribution and use. To date, 33 gene conservation stands have been established in 6 zones throughout the country. The aim is that the genetic variation within a particular species is conserved through a network of conservation stands in different gene ecological zones representing populations of different genetic composition. *In situ* conservation is complemented in some circumstances by *ex situ* activities. Furthermore, the use of threatened priority species within tree planting activities will be encouraged.

**Lao and Cambodian Community Involvement in Seed Source Establishment and Conservation**

The need to protect and conserve natural resources parallel with social and economic development has been widely acknowledged. Development and conservation efforts should be improved by integrating conservation also with short-term benefits for local users of natural resources (Isager *et al*. 2002). In Lao PDR and Cambodia local people and local forest authorities are directly involved in seed source identification, establishment, and management as well as drafting and signing of agreements. The villagers benefit from seed source management by permission to collect and sell quality tree seed. The income may contribute to the alleviation of poverty in communities, and simultaneously provide an incentive to protect the seed sources. Thus local people are becoming local custodians of forest genetic resources.

The Lao Tree Seed Project (LTSP), together with the Forest Research Centre at the National Agriculture and Forestry Institute in Lao PDR has supported this model for conservation of indigenous species to ensure a sustainable supply of quality seed for future plantings. Guided by gene-ecological zoning 100 seed sources covering 21 priority tree species were established in national conservation forest areas. The location of seed sources depended on the accessibility for management and seed collection by nearby villages and desired characteristics of mother trees of the priority species.

The following process was developed as model for involvement of local people in Lao PDR: Potential seed sources are identified during surveys. Visits are made to provincial and district forest offices providing an entry point to contact villages near potential stands. Visits are arranged to meet representatives of village groups (headman, assistant headmen, village forester, village security, village women’s group, etc). Villagers are introduced to the objectives (quality seed, conservation) and relevance to villager’s objectives (income generation) is explained. The process is a flexible learning–by-doing method adapting to each situation (Greijmans *et al*. 2004).

To increase involvement by local villagers, a participatory village forest mapping exercise is carried out to select seed sources. Villagers are urged to provide feedback, but also to ask questions on the model. In this case, intensity of discussions varied according to people’s level of education and welfare but also on ethnicity. Questionnaires are used to gather information for management plans on issues pertaining future seed collection, seed sale, management and conservation. A management agreement is drafted and explained to villagers, outlining responsibilities and rights, to be discussed and adapted when necessary. Seed sources are then established and documented using village knowledge. An agreement is prepared for signing by the village headman. District and provincial forest offices are invited to co-sign the agreement, which is then forwarded to the Ministry of Agriculture and Forestry to be registered under a decree (Greijmans *et al*. 2004).

Likewise, participatory approaches to establishment and management of tree seed sources are currently being piloted in Cambodia. The Forestry Administration (FA), in collaboration with the Cambodia Tree Seed Project has established a number of indigenous tree seed sources throughout the country. Currently, most of the seed sources are under the management of local levels of the FA, but experience indicates that local people are sometimes better placed to manage such areas. Furthermore, a participatory approach has a potential to contribute both to poverty reduction, and sustainable forest management (CTSP 2004).

The first lessons learned in Laos and Cambodia concurrently indicate that the participation of villagers in seed source management and forest genetic conservation can enable effective management of forest resources. Commercialisation and marketing of quality tree seed alone, is however, likely to raise limited income for villagers. In both countries knowledge on marketing is limited. Demand for quality seed is weak and seed users are not clearly identified. Thus, most costs are currently incurred by supporting agencies (FA/CTSP 2003b).

The examples highlight the importance of widening marketing opportunities for villagers to a broader range of forest products, and to adding seed source management and forest gene conservation into ongoing community forestry/development activities in order to secure greater potential for sustainability.

## *Ex situ* conservation

*Ex situ* conservation means the conservation of components of biological diversity outside their natural habitat (UNCED 1992). The *ex situ* conservation methods for tree species include storage in seed genebanks, as well as living conservation stands: field genebanks (*ex situ* conservation stands), botanical gardens and arboreta as well as genebanks for seed and pollen, clonal banks, *in vitro* genebanks (including slow growth storage and cryopreservation) and DNA banks (e.g. UNCED 1992; Chin 1994; ITTO & RCFM 2000d; Engelmann *et al*. 2003). Provenance trials, seed orchards, seed production areas and breeding populations are also usually counted in the lists of *ex situ* conservation areas. Commonly, the aim of *ex situ* storage for conserving woody species is to maintain the initial genetic and physiological quality of the germplasm until it is used or regenerated (Theilade & Petri 2003).

Efforts for FGR conservation *in situ* or *ex situ* are often included as a component in tree improvement programmes. So far, *ex situ* conservation stands specifically designed for long-term FGR conservation have been established for a small number of species. Theilade (2003) has provided a review of some early and some recent experiences of conservation of genetic resources of tropical trees in living stands (field genebanks). Some botanical gardens and arboreta have started collections for conservation purposes but the number of individuals is generally inadequate so safeguard long-term conservation objectives. Seed genebanks are often not an appropriate conservation method for most tropical forest species as most of these produce recalcitrant seeds that cannot be stored for long (e.g. Chin 1994). It has been estimated that globally only about 100 tree species are conserved adequately *ex situ* and these are almost exclusively species whose genetic resources have been collected for domestication programmes. Despite the difficulties, *ex situ* conservation could be an important or even necessary component of the conservation strategy for many of the highly valuable and rare species and gene pools. As habitat destruction in tropical forests proceeds, even thousands of tree species will depend on conservation outside protected areas, i.e. in managed forests and agricultural landscapes through domestication, or *ex situ* in seed banks or field genebanks, etc. (Theilade 2003).

Seemingly, in many countries of the region the national level information on all *ex situ* conservation stands and projects is not kept up to date. Surveying the status of conservation stands requires a sustained effort and may be costly. It is generally not a priority activity for strained forest departments and research institutions. Arboreta and botanical gardens are in general well documented, as are seed genebanks. The case may not be the same for *ex situ* conservation stands. Practical guidelines for *ex situ* conservation of tropical timber trees have been developed for some species - see e.g. ITTO & RCFM (2000 c and d) for examples. However, the implementation of many of these existing strategies may be slow due to e.g. financial restrictions.

### *Ex situ conservation stands*

The objective of the establishment of *ex situ* gene conservation stands is the establishment and maintenance of populations, which are large enough to prevent excessive inbreeding and differentiated from each other with regard to adaptive traits (Finkeldey 1996). *Ex situ* stands are in many cases the most practical method for conservation, especially where storage is not technically possible or facilities are not available. So far, most *ex situ* conservation stands of tropical trees have been established for pioneer species, one of the early examples being the FAO-coordinated programme on *ex situ* conservation of Central American pines and *Eucalyptus* spp. (Pilegaard & Theilade 2001).One exception is the trial plantings of indigenous hardwoods for evaluation purposes established since the beginning of 1900s in Indonesia. Perum Perhutani, a state-owned forestry enterprise, has established conservation stands for various teak varieties collected from all geographical areas in Indonesia in the 1990s. The Centre for Forest Biotechnology and Tree Improvement Research and Development (CFBTI) has an *ex situ* conservation programme as part of tree improvement activities for a number of tree species. The Centre for Forest and Nature Conservation Research and Development (CFNC) has already established *ex situ* plots for a number of dipterocarps in Java during the 1950s (Masripatin *et al*. 2004). The Indonesian experience is valuable as this is one of the few cases where we can follow *ex situ* stands of tropical hardwoods for a period of more than 60 years. More recently an ITTO-supported project focused on *ex situ* conservation of two model species namely *Shorea leprosula* in well-drained lowland forests and *Lophopetalum multinervium* in swamp forests. The project, which was initiated in 1998, established 81.5 ha of *S. leprosula* conservation cum seed production areas, originating from 9 populations and 62.5 ha of *L. multinervium* from 4 populations. The unique feature of the project is the incorporation of breeding concept in the conservation of FGR. Thus, whilst collecting seeds for conservation plots, some were set aside for progeny test.

According to Lee & Krishnapillay (2004), in Malaysia, national research efforts have concentrated on the improvement and sustainable development of agricultural crop species. Nevertheless, valuable work has been carried out on conserving the genetic resources of forest species as well. The largest groups of forest plant species under *ex situ* conservation are orchids (1639 species), followed by fruit trees (434 species), timber species (364 species) and medicinal plants (115 species). Saw & Raja Barizan (1991) have provided the latest comprehensive list of *ex situ*-conserved species in the country.

As an example, in Vietnam, many important tree species have been involved in the national *ex situ* conservation programme (Tables 3 and 4).

Table 3. Arboreta and bambuseta in Vietnam

| Location | Number of species | Area |
| --- | --- | --- |
| Cau Hai, Phu Tho | 250 tree and 80 bamboo species | 20 ha |
| Trang Bom, Dong Nai | 120 tree and 20 bamboo species | 8 ha |
| Lang Hanh, Lam Dong | 20 rare tree species | 10 ha |
| Mang Linh, Lam Dong | 40 rare tree species | 10 ha |
| Cuc Phuong, Ninh Binh | 100 tree species | 100 ha |

Table 4. *Ex situ* conservation stands in Vietnam

| Species | Number of seed sources | Number of trees or area |
| --- | --- | --- |
| *Erythrophloeum fordii* | 8 | 2.5 ha |
| *Dipterocarpus retusus* | 2 | 2.0 ha |
| *Madhuca pasquieri* | 2 | 6 ha |
| *Calocedrus macrolepis* | 2 | 2000 trees |
| *Fokienia hodginsii* | 1 | 2000 trees |
| *Taxus wallichiana* | 4 | 1000 rooted cuttings |
| *Shorea falcata* | 1 | 3000 trees |
| *Hopea cordata* | 1 | 500 trees |
| *Hopea reticulata* | 1 | 500 trees |

Establishment of *ex situ* conservation stands of more indigenous species is wanting but this requires considerable time, money and knowledge. In collaboration with the Biotechnology Institute, The Forest Science Institute of Vietnam has carried out research using RAPD and Chloroplast DNA for evaluating relatedness of species as well as genetic diversity of some species and provenances. Such data is useful in setting priorities and selecting species and populations for conservation (Quach Thi Lien *et al* 2004).

In the Philippines, *ex situ* conservation efforts for timber trees generally involve field genebanks or plantations for species and provenance trials (Razal *et al.* 2004). Species and provenance trials and establishment of seed orchards have long been conducted by the DENR for species of *Acacia, Casuarina, Eucalyptus, Gmelina, Pterocarpus, Pinus, Swietenia, Xanthostemon* and other multipurpose species (Garcia 1999). The private sector has also initiated some activities in *ex situ* conservation of industrial plantation species. The DENR has also established seed storage and testing centre at its Central Office (Razal *et al* 2004).

Thailand has long been involved in the process of FGR conservation. The process was started with Thai-Danish cooperation in tree improvement, i.e. teak in 1965 and pines and fast growing species improvement in 1969 (Sumantakul 2004). *Ex situ* conservation of tropical pines was initiated in 1973 and, since then approximately 800 ha of provenance *cum* seed stands have been established in the highlands of northwest Thailand. The Royal Forest Department (RFD) in collaboration with the Danced implemented a programme for *ex situ* conservation of eight major timber species during 1989-93. The indigenous species conserved in gene conservation stands at different research stations include *Tectona grandis, Pinus merkusii, P. kesiya, Dipterocarpus alatus, Dalbergia cochinchinensis, D. oliveri, Xylia xylocarpa* var. *kerrii, Pterocarpus macrocarpus, Shorea roxburghii, Afzelia xylocarpa* and *Hopea odorata* (FORGENMAP 2002; Sumantakul 2004).

In other countries, such as Cambodia and Lao PDR, the establishment of *ex situ* stands is a relatively new activity. The main focus of conservation efforts is on indigenous species. In Cambodia e*x situ* conservation is underway to complement forest gene conservation in natural forests. The establishment of *ex situ* stands also provides an important source for research, and a number of *ex situ* trials are currently being conducted by the Cambodia Tree Seed Project (CTSP) on the growth, yield, fire tolerance and regeneration capability of selected indigenous species and provenances (CTSP 2005). The Kbal Chhay Protected Watershed area in Cambodia has been selected as the location for several *ex situ* plots to test the potential of species and provenances in watershed restoration. Seeds have been collected from different gene-ecological zones, and planting began in 2003. A seed orchard of eight species (*Afzelia xylocarpa, Aquilaria crassna, Hopea odorata, Tarrietia javanica, Shorea vulgaris, Dipterocarpus turbinatus, Pterocarpus macrocarpus* and *Azadirachta indica)* was established. Unfortunately, fire swept through the *ex situ* area in 2005. However, some of the species, such as *Pterocarpus macrocarpus* have shown regeneration after the fire. In addition, *ex situ* stands of *Afzelia xylocarpa, Dalbergia bariensis, Dalbergia cochinchinensis, Pterocarpus macrocarpus* have been established as seed production areas. An *ex situ* species elimination trial of 21 species has been established by the CTSP to identify the species best suited for restoration of Kbal Chhay Watershed. All species are currently showing high survival rates and fast growth. These early results are of great interest as the seedlings are growing in open areas, contradicting strong assumptions that indigenous ‘forest’ seedlings cannot grow without shade (CTSP 2005).

As concluded by Theilade (2003) the most important technical challenge for long-term *ex situ* conservation of trees in living stands is the regeneration of mature stands. Regeneration protocols need to be developed and practices implemented as collections mature to ensure continuity. Flowering and fruiting may be distorted in the different ecological condition in the new environment. Many *ex situ* conservation stands are abandoned within 5-10 years of planting as project cycles finish. Therefore, relatively many new *ex situ* stands can be found but few have proven their worth beyond 10 years of age and even fewer (if any) have been regenerated so far.

Another common challenge in *ex situ* stands is how to maintain the necessary data over long periods. One benefit of conservation of trees in *ex situ* stands is e.g. that the location of stands can be selected to minimize risks of natural disasters and encroachment etc.

Generally, the design of *ex situ* stands has been that of plantation forests, i.e. even-aged stands of one species (monocultures). This is only feasible if resources are available for intensive management and regeneration. Moreover, this design may not be suitable for some late succession species. For these, Theilade (2003) recommends establishment of larger areas with a mixture of species to create as close to natural conditions as possible to support the long-term stability of the system with minimum needs for management interventions as long-term funding for FGR conservation cannot be secured. Such systems, as a kind of forest rehabilitation have been tried in Brazil (Sebbenn *et al*. 2001). Ideally, *ex situ* conservation should merge with *in situ* conservation as conserved genetic material is brought into use in reforestation and land rehabilitation efforts.

## *Breeding programmes for indigenous species*

The deterioration of natural forest has had significant impact on the economy as well as immediate environmental impact. Government policies have been adopted to reverse the deteriorating trend of natural forest of tropical countries including the establishment of commercial plantations. It is in the commercial plantation establishment where the issue of high quality seeds or planting materials produced by long term breeding programmes becomes critically important. Most effective improvement programs are fully integrated with large-scale planting programs. This ensures that breeders work closely with end users to determine appropriate breeding objectives, and cost savings are achieved by planting out their breeding trials as an integral part of the plantation program. Trees in the trials end up being used for wood production after they have served their research function.

The essential element of breeding is population improvement by a combination of a particular type of selection and a particular type of mating starting with a well-adapted genetic base (Eldridge *et al.* 1993). Broad genetic diversity is essentially important for genetic conservation as well as genetic improvement. The presence of genetic diversity in a population provides the basis for species adaptation. In a breeding program, genetic improvement depends upon the existence, nature and extent of the genetic variability available for manipulation.

As an example, in Indonesia breeding programmes of some of the country’s indigenous species are currently in progress. One of the most notable examples is the progeny test of *Shorea leprosula* (22 ha of 502 families from 7 populations). This test was established in 1998 as part of an ITTO-supported project. It is expected that in 15 to 20 years from now, genetically improved seeds of *S. leprosula* would be available for plantations. As an interim measure, untested clones could be used for mass propagation by cuttings. Despite the slow growth of many of the indigenous species, and long interval of generation turnover of breeding populations, breeding programmes of the native species have to be implemented if productive plantations are to be expected.

Generally, most breeding programmes are targeted for large-scale industrial plantations, as is the case with *S. leprosula*. However, in Bali, Indonesia a pioneering work on conservation and breeding of indigenous species for community forestry is in progress. The species of interest are *Zanthoxylum rhetsa, Manilkara kauki, Alstonia scholaris* and *Wrightia pubescens* used by local craftsmen for various handicraft products. So far some 20 ha of seed orchards and progeny tests of the four species (5 ha each) have been established.

If compared to the rapid progress of the breeding programmes of the popular exotic species such as acacias and eucalypts, breeding of indigenous species is well behind. This is partly due to the fact that plantation areas of the indigenous species are very small, in contrast to the exotic species, which have been planted over millions of hectares. Demand for high quality seeds has been the driving force of the breeding programmes. Now that a programme on establishment of *Shorea* plantations is in place, interest in breeding of the species is also increasing.

## *Storing genetic diversity of trees*

The aim of *ex situ* storage is to maintain the initial genetic and physiological quality of the germplasm until it is used or regenerated. In agriculture, most crop species are conserved *ex situ* using seedbanks, field genebanks and, in certain cases, tissue culture. In contrast, forest species, especially trees reach reproductive maturity at a late stage and have a long generation cycle; the preferred conservation approach is to incorporate *in situ* conservation principles into sustainable forest management, increasing the areas of protected forests and in some cases complementing these with conservation stands. In addition to *ex situ* conservation of trees in living stands it is possible to store seeds, pollen, tissue in *in vitro* cultures or even DNA in DNA libraries.

Most agricultural crops have seeds that can be dried and stored at low temperatures for years without losing the ability to germinate. These have been termed orthodox seeds. However, many tree species, particularly in the tropics, have seeds that are difficult to store because they do not tolerate drying and have therefore been termed recalcitrant seeds. The use and conservation of many valuable tropical tree species in planting and conservation programmes is hindered by short seed viability. Improved techniques are a key to the increased use and conservation of many species.

To safeguard the storage of non-orthodox species, it may be necessary to turn to the other techniques. Cryopreservation refers to seed storage at ultra-low temperature, usually in liquid nitrogen (ca. 196 ºC). Coupled with *in vitro* culture, this technique often represents the only safe and cost-effective option for storage of non-orthodox species (e.g. Engelmann 2004). For example, the seeds of mahogany (*Swietenia macrophylla)* or neem (*Azadirachta indica*) are relatively small and tolerant to desiccation, and can thus be cryopreserved directly after partial desiccation (Hu *et al*. 1994; Marzalina 1995; Berjak & Dumet 1996). In cases where seeds are not amenable to cryopreservation, excised embryos or embryonic axes could be used. Globally only few institutions are working the development of cryopreservation of forest trees – even less in the tropics. Much of the work done so far has been focusing on developing cryopreservation protocols for fruit tree species (see e.g. Chaudhury *et al*. 2003). In Southeast Asia, the Forest Research Institute Malaysia (FRIM) has an active programme studying the cryopreservation of tropical trees and other forest species. In addition, the CFBTI in Indonesia has done efforts to cryopreserve ramin (*Gonystylus bancanus*). However, the research results have not yet been applied in actual conservation.

The Forest Research Institute Malaysia (FRIM) has studied the cryopreservation of some forest species. These include *Acacia mangium, Dendrocalamus membranaceus, D. brandisii, Dipterocarpus alatus, D. intricatus, Tectona grandis* and *Thyrsostachys siamensis*, using whole seeds. In addition, embryonic axes have been used as a source of cryopreservation of *Calamus manan, Shorea ovalis, S. parvifolia, S. macrophylla* and *Sterculia* spp. Apart from the forest species, FRIM has also studied the cryopreservation of certain urban forestry species, such as *Adenanthera pavonina*, *Bambusa arundinacea*, *Cassia nodosa, C. spectabilis, Casuarina sumatrana, Hopea odorata, Lagerstroemia* spp., *Leucaena leucocephala, Pterocarpus indicus* and *Swietenia macrophylla* as well as other trees such as *Albizia falcataria*, *Alstonia angustiloba* and *Peltophorum pterocarpum.*

Results show that whole seeds of most orthodox and intermediate species could be cryopreserved without many problems since the moisture content can be reduced to less than 10%. In contrast, the whole seeds of truly recalcitrant species cannot be cryopreserved. However, when embryos or embryonic axis of *Shorea* spp. were used, some recovery between 5 to 10% has been observed. Cryopreserved embryonic axes of *Hopea odorata* have shown 15% recovery. Efforts to further improve the cryopreservation protocols for recalcitrant species are in progress.

With species for which attempts to freeze whole embryos or embryonic axes have proven unsuccessful, various authors have suggested using shoot apices sampled on the embryos, adventitious buds or somatic embryos induced from embryonic tissues (Pence 1995; Berjak *et al*. 1996). This might be the only solution for species that lack well-defined embryos. However, in this case, more sophisticated tissue culture procedures have to be developed and mastered. The disadvantage of cryopreservation is the overall difficulty of regeneration of whole plants. *In vitro* conservation involves the maintenance of explants in a sterile, pathogen-free environment and is widely used for the conservation of species which produce recalcitrant seeds or no seeds at all, or for material which is propagated vegetatively to maintain particular genotypes (Engelmann 1997). This technique has been applied for multiplication, storage and the collection of germplasm material for more than 1000 plant species (Bigot 1987). *In vitro* techniques can be effectively used for collection, multiplication and storage, particularly with problematic species (Engelmann 1997). Techniques have been developed to introduce recalcitrant seeds and vegetatively propagated material *in vitro*, under aseptic conditions, directly from the field (Withers 1995). This approach will allow germplasm collections to be made in remote areas in the case of highly valuable recalcitrant seeds, for example. However, many conservation programmes are unable to meet requirements for relatively sophisticated equipment, reliable electricity supply and trained staff.

Tissue culture through *in vitro* techniques has been widely studied in *Swietenia macrophylla, Shorea leprosula, Shorea ovalis, S. parvifolia, S. macrophylla, Hopea odorata* and *Calamus manan* at FRIM.

Seedling conservation of young seedlings arrested in their development by storage at low temperature and/or under low light intensity has been experimented with *Symphonia globulifera* and *Dryobalanops aromatica* (Corbineau and Côme 1986; Marzalina *et al*. 1992). In addition Krishnapilly and Tompsett (1998) stored seedlings of 17 dipterocarp species in a seedling chamber at the temperature of 16°C with 80% RH. It was found that the seedlings developed slowly in the chamber, with the height of 20-25 cm over the storage period. Meanwhile, survival percentage was between 60 and 80%, depending on species.

The importance and potential of DNA storage is rapidly increasing. DNA from the nucleus, mitochondrion and chloroplasts is now routinely extracted. These advances have led to the formation of an international network of DNA repositories for the storage of genomic DNA (Adams 1997). This technique is efficient, simple and takes up little space. The main disadvantages, besides demanding requirements for capacity and equipment, lie in problems with subsequent gene isolation, cloning and transfer and regeneration of plants.

The design of any *ex situ* conservation programme, and the decision about which technologies to use, must start from considerations of the biological material in question: why do we want to conserve it, and how is it going to be used in the future? Unless *ex situ* material is regenerated and at some stage brought into use, its conservation has no meaning.

## *Conclusions*

Despite the efforts made so far, the genetic diversity of most known and potentially useful tropical tree species is not yet adequately conserved. International donor funding for forestry and forest conservation has decreased dramatically since the peak years of early 1990s. Another increase could be anticipated when the importance of forest conservation will be re-realized. An increase in both national and international efforts is necessary for successful genetic conservation of useful plantation and reforestation species in Southeast Asia. Some international commitments, such as the Global Strategy for Plant Conservation, with concrete targets may be instrumental in directing future institutional support for activities.

The development of national forest gene conservation strategies is underway in a number of countries, outlining national priority species for conservation and suggesting tools for policies, planning and protection. Where more sophisticated genetic tools are unavailable, conservation strategies can be developed effectively using gene-ecological zonation. The model is used to estimate patterns of genetic variation within species assuming that similarities of ecological conditions imply similarities of genetic constitution. The first step in developing conservation strategies is a field survey to develop necessary distribution maps and assessment of conservation status of priority species. The aim is that the genetic variation within a particular species is conserved through a network of conservation stands in different ecological zones representing populations of different genetic composition. Gene-ecological zoning has proved to be a practical and cost-efficient tool for gene conservation as it can often be based on available data. Even though management of *in situ* conservation stands is the primary tool for FGR conservation, in many cases this needs be complemented with *ex situ* activities (*ex situ* stands and storage systems). Very importantly, the use of threatened species in tree planting and rehabilitation programmes should be further encouraged.

Currently, most tree seed sources are under the management of national institutions but recent experience indicates that participatory approaches may contribute both to poverty reduction, and effective forest management. A participatory approach to establishment and management of tree seed sources are currently being piloted in e.g. Lao PDR and Cambodia. Opportunities for villagers to market a broad range of forest products, including tree seed, are found essential to secure sustainability. Hence, seed source management and forest gene conservation may very well be included in ongoing community forestry/development activities.

*Ex situ* conservation is sometimes necessary to maintain genetic and physiological quality of germplasm until it is used or regenerated. *Ex situ* conservation of tree species include living conservation stands, storage in seed banks, as well as in genebanks for pollen, *in vitro* slow growth, cryopreservation, and DNA banks. Provenance trials, seed orchards, seed production areas and breeding populations may also function as *ex situ* conservation stands. Different *ex situ* conservation projects, if successfully developed, could provide a secure and timely supply of planting material of otherwise difficult species and thus help to bring threatened species back into use.

Broad genetic diversity is essential for conservation as well as improvement and sustainable use of

FGR. Despite the slow growth and long generation turnover of breeding populations of many species indigenous to S.E. Asia, breeding programmes of several hardwoods are on the way. These programs all depend upon extent of genetic variability available for manipulation. So far, no more than a fraction of all potential species and genepools are included in improvement programmes.

Hopefully the implementation of national FGR conservation strategies will gain momentum in the years to come and be complemented by regional planning and coordination. Only then, healthy and diverse forest genetic resources will be available for future planting and restoration efforts.

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