Genecological zonation as a tool in conservation of genetic resources of Teak (*Tectona grandis*) in Thailand

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Summary
The Thai teak forests are under pressure. They have for decades suffered from overexploitation and conversion to agricultural land. Only fragments of the original teak forests remain at present, mainly in a few protected National Parks.

The ecological conditions vary within teak’s natural distribution area in Thailand. Genetic variation between stands within Thailand is therefore possible as a result of adaptation to different environmental conditions, or following thousand years of separation.

A conservation plan for teak in Thailand has been developed with the objective to protect this precious genetic resource for future use (Graudal *et al.* 1999). The conservation plan is based on so-called genecological zonation where variation in ecological conditions within the distribution area is investigated and uniform zones are formed based on available data. Based on this zonation, it is recommended to conserve a network of conservation stands rather than a few populations. The rationale of this strategy is described in more details in Graudal *et al.* (1999), and the present presentation give a summary of the factors discussed in Graudal *et al.* (1999). The work is a result of a joint effort between Royal Forest Department (FORGENMAP) and Danida Forest Seed Centre.

Introduction
Teak is one of the most important timber species of the world. High quality teak attain prices of several thousand US $ per m³ on the world market (TeakNet, 1997). Teak wood has therefore been heavily exploited from the natural forests for decades. In Thailand, it used to be one of the most important export commodities of the economy. Kjaer and Foster (1996) have estimated the yearly value production of teak plantations on suitable sites to be more than 7000 US $ per ha. The degradation of the natural forest and the widespread use of teak make conservation of the genetic resources of teak a major international concern.

Genetic resources are here considered as genetic material of actual or potential value. Teak forest in general consists of genetically diverse trees, and substantial genetic differentiation between populations - and between single trees within populations - has been found in genetic studies (cf. Kjaer *et al.*, 1995). Improved growth, quality and adaptability can be achieved through careful development and selection of the best genetic material when raising plants for a given planting (cf. Kaosa-ard, 1996; Kjaer & Foster, 1996). However, tree improvement requires the presence of genetic diversity, and genetically broad populations should therefore be maintained as a basis for present and future domestication. Lost diversity means lost options for future use.

An important objective of gene conservation is also to secure the ability of the species to adapt to environmental changes. This is especially important in the light of likely climatic changes in the years to come.
The loss of natural teak forest in Thailand

Teak grows naturally in the Northern region of Thailand. It is generally limited to mixed deciduous forest in the altitudinal range of 100-900 m a.s.l, (Mahapol, 1954; Champion and Seth, 1968), i.e. the lower altitudes which also are the areas most suitable for conversion to permanent agriculture. Also, the fertile alluvial soils found in large parts of the natural teak forest are very suitable for agriculture. The teak forests of Thailand have therefore been put under tremendous pressure for conversion to permanent farm land over the last decades.

Official data reports a decline in the forest area in the Northern region of Thailand from 11.6 million ha (69% forest cover) in 1961 to 7.4 million ha (44% forest cover) in 1995. Still, the forest cover in the Northern region is relative high compared to data from the whole of the Thai Kingdom, where it has declined from 53% in 1961 to 26% in 1995 (RFD, 1996).


The distribution of the mixed deciduous teak forest in Northern Thailand around 1960 is compared to the situation around 1990 in Fig. 1 (based on RFD 1962, 1983, 1993 and 1995, modified according to RFD 1994; cf. also Collins et al. 1991). The distribution around 1960 are probably fairly close to the original natural distribution area, although occurrence of teak in the mixed deciduous forest to some extent had been reduced prior to 1960 due to illicit felling and influence from shifting cultivation (Mahidol University and RFD, 1995). However, it is difficult to separate the recorded area of mixed deciduous forests into teak bearing and non-teak bearing forest. The remaining area of teak bearing forest was e.g. estimated to only 20 000 km² in 1957 (Loetch, 1958). Certainly, it can be concluded that a large reduction has taken place during the last 30 years, indicating that the conservation status of teak has gradually deteriorated in that area.

There are no virgin teak forests left in Thailand. Selective logging has been practiced in all native teak forest of Thailand including the now protected areas. After the 1989-logging ban, illicit felling has to some degree continued in reserved forests (Mahidol University and RFD, 1995). In many of the remaining teak forests outside the protected areas, hardly any straight trees are left following intensive log poaching (Kjaer & Suangtho, 1997). One must therefore assume that the genetic quality in terms of commercial use (mainly stem form) has been degraded in the forests outside the protected areas. The protected forests have also been poached to some extent, but here genetic effects from the selection are probably much less pronounced.
The role of protected areas in conservation of teak in Thailand

In Thailand, a network of national parks and wildlife sanctuaries contributes to the conservation of forest genetic resources (cf. e.g. Collins et al. 1991). Some of the remaining teak forests are located within protected areas, but large tracts are without such protection (Fig. 2). Still, small overlaps are found in most parts of teaks’ natural Thai distribution.

Mahidol University & RFD (1995) estimates that at present only 15 areas with more than 10 km² of mixed deciduous teak forest exist in protected areas, mainly in 7 national parks (Thung Salang Luang, Namtok Chatrakhan, Mae Yom, Phu Miang-Phu Thong, Sri Satchanalai, Taksin Maharat, Mae Ping) and one Wildlife Sanctuary (Mae Yuam Fang Khwa). Only Mae Yom National Park include a fairly large area with natural teak forests, but the network of remaining teak forests within the protected areas still plays an important role as will be discussed below.

Teak plantations in Thailand as a resource for conservation

Teak has been planted in Thailand since the beginning of the 20th century, but on a large scale only since the 1960’ties. In recent years, private planting has been initiated on a large scale and more teak trees are today planted by private farmers than by public organisations (Kaosa-ard, et al. 1998).

The value of plantations as genetic resource conservation areas depends on whether the origin and genetic composition of the planting material is known. This is in general not the case in the Thai teak plantations where seeds often are collected along roadsides or from urban plantings. Still, many old Thai teak plantations are founded on seed collections from the natural forest prior to their recent severe degradation. The plantations therefore represent a valuable gene pool to be considered in gene conservation measures.

Gene conservation in the teak breeding programme

Tree improvement of teak was initiated in Thailand more than 40 years ago (Kaosa-ard et al., 1998). At present, approximately 350 selected plus trees are included in the breeding population and conserved in multiplication gardens and clonal seed orchards. Originally, 100 plus trees were selected of which 60 have been extensively used in the seed orchards. Later, an additional 250 plus trees have been selected. All plus trees have been chosen in good stands of high commercial value. Some of these stands have later disappeared completely, or have been severely logged. Therefore, the clones in the breeding programme constitute an important ex situ genetic resource. The breeding population thus represents a unique gene pool of trees selected in important parts of the distribution area. There are parts of the
distributional area from which only few - or none - plus trees are included, and additional conservation measures are therefore required (Graudal et al. 1999). Also, at present the breeding population mainly serves as a so-called static conservation measure where no natural selection acts within the gene pool. For long term conservation a more dynamic system is preferred (Eriksson et al. 1993), where the gene pools can adapt to changes in climate and react to new pests through natural selection.

**Genetic variation of teak in Thailand**

It is important to know the nature of the genetic resource to be conserved. Reliable information on the distribution of genetic variation - within and between geographic regions - is therefore important in order to establish an effective network of conservation stands.

The genetic variation can be assessed by different techniques. It is possible to study morphological and metric characters in field trials or study variation in biochemical and molecular markers in the laboratory. Also, it is to some extent possible to predict genetic variation patterns from ecogeographic variation. In Thailand, data is available from field trials. However, variation in biochemical markers has recently investigated. The utilisation of this information is discussed below.

**Field trials**

Field trials are the most direct way to estimate the potential of different seed sources, and assessed adaptive genetic variation is the still best basis for conservation activities (Eriksson, 1995).

Six Thai provenances are compared in an international provenance trial at Pha Nok Kao, Khon Kaen province. Results in terms of both survival, vigour, stem from, persistence of axis, epicormic branches, bark thickness, wood density and physical characteristics have been published by Keiding et al. (1986), Kjaer et al. (1995 and 1996), and Kaosa-ard (1992). The joint information from all these traits has been analysed by multivariate statistics in order to look for ‘clustering’ of provenances in groups with similar performance (Kjaer et al. 1996). Only six Thai provenances are included in this trial, and the amount of information on the genetic variation of teak in Thailand that can be deduced is therefore limited. Still, a tendency to differences between eastern and western provenances was revealed in the multivariate analysis (Graudal et. al. 1999).

An older national provenance trial comprising 30 Thai provenances was established in 1966 at Huay Tak, near Ngao, Lampang Province. The geographic representation of Thai provenances in this trial is very good compared to the trial in Pha Nok Kao. The trial was assessed at 15 years of age for DBH, height, height of clear bole, and flowering (Kaosa-ard, in prep). This data has been analysed with the objective to look for genetic patterns (Kjaer, 1999). The number of traits in this analysis is low compared to the observations from the international trial at Pha Nok Kao. Also, the environmental heterogeneity has been relative large in Huay Tak. Still, important information can be gained from this trial in relation to conservation (Kjaer, 1999):

- Significant differences seem to exist within the natural distribution area of teak in Thailand, supporting that gene conservation should sample genetic variation on population level (*i.e.*, include several populations)
- Observed differences at Huay Tak are to a large extent found between stands within floristic region. This indicates relative complex genetic pattern.
- Still, a tendency to East-West (but also north-south) clinal variation are observed (Kjaer, 1999), which supports the observations from the international trial.

To conclude, the existing provenance trials in Thailand suggest that genetic differentiation may exists between populations within Thailand. An apparent pattern of clinal East-West (and also to some extent north-south) differences are observed, although large variation are found between sources within provinces.
Genetic markers
Biochemical and molecular markers offer fast surveys of genetic variation within and between populations.

Genetic markers are normally considered not to be influenced by natural selection. Important genetic differentiation following divergent natural selection in a few generations may therefore not be detected by the markers (Karhu et al. 1996). This is supported by the fact that several studies of forest trees, including teak, have shown larger differentiation between adaptive traits than between biochemical markers (Kjaer et al. 1996). This is a serious draw-back by the use of genetic markers. Still, genetic markers can contribute important information on migration routes, hybridisation, and breeding systems.

A study of variation in genetic markers on a large number of populations in Thailand has been finalised recently (Changtragoon, pers. comm.). This study includes several Thai populations and can supply important information on likely historic migration patterns, amount of pollen flow, and breeding patterns of teak. This information will be included in the conservation plan once it has been analysed.

Ecogeographic variation
A study of clinal variation in ecological parameters within the species’ distributional range provides knowledge of the ecogeographic variation of the species. It is generally assumed that similarity of ecological conditions implies similarity of genetic constitution. This is based on the assumption that adaptation to local conditions is the major force in creating population differences. This is not always a valid assumption (Namkoong, 1969) and an ecogeographical survey will therefore only provide a first indication of possible genetic variation.

The natural vegetation of Thailand has been surveyed and mapped several times (Ogawa et al. 1961; RFD 1962, 1983, 1993 and 1995; cf. also Smitinand 1977, Collins et al. 1991 and Boontawee et al. 1995). Good topographic maps exist (Royal Thai Survey Department 1978-95; cf. also Mahapol 1954), climatic data are available (Meteorological Department, Prime Ministers Office; cf. also FAO 1987, Kaosa-ard 1983, Eis 1986), and soils have been surveyed (FAO-UNESCO, 1979; Mooremann and Rojanasoonthon, 1968).

A general seed zone system for Thailand prepared by Eis (1986). This zonation is based on topography, precipitation (amount and distribution) and temperature. A climatic seed zone system specifically for teak based on temperature and precipitation has been constructed by Kaosa-ard (1983). These zones indicate mainly North-South variation.

Genecological zonation of natural teak in Northern Thailand
A genecological zone can be defined as an area within which it is acceptable to assume that populations are genetically similar. Such zonation is based on a compromise between the variation in ecological factors and expectations of gene flow. The zone should have sufficiently uniform ecological conditions to assume that no important divergent selection has taken place. The zones should not be too small, because pollen flow between neighbouring zones would then be likely to prevent that any genetic differences develop between populations from the different zones. On the other hand, the zones should not be too large, because then important genetic differences may exist between populations within each zone. The construction of genecological zones is described by Graudal et al. (1995), and Graudal et al. (1997).

Factors used for zonation should reflect, directly or indirectly, divergent natural selective forces. Genetic races may e.g. have developed, if a species grow naturally in both dry areas and wet areas - given that these areas are genetically isolated (only limited exchange of pollen and seed). Precipitation is therefore one such parameter that should be considered. Factors often considered are climatic parameters, variation is soil, topography and natural vegetation. Genecological zonation may be prepared as one
common system for several species or as a species-specific system. It will usually be based on existing data and maps of vegetation, topography, climate, and soil. If information from provenance trials and genetic marker studies is available, it may be used to test the validity and adjust the zonation system, if required.

Based on the examination of topography, climate and vegetation discussed above a total of five genecological zones have been drawn (see Graudal et al. 1999 for details). The result is shown in Fig. 3.

**Figure 3. Separation of the remaining teak forests in Northern Thailand into 5 genecological zones. The numbers 1-15 show location of 15 stands preliminary identified for gene conservation. Here after Graudal et al. (1999).**

Genecological zonation is not something fixed, but is subject to continuous revision as more information becomes available. Revision is discussed in more detail by Graudal et al. (1997). In Thailand the possible additional information from genetic markers mentioned above may be of particular value for such revision.

**A network of gene conservation areas for teak in Thailand.**

Comparing the geographical distribution of teak with the genecological zones provide the overall framework for sampling of conservation populations. To cover the genecological variation, at least one population per zone should be identified. Replication of conservation populations/samples is necessary to minimise the risk of loss due to unforeseen external events. Also, the indication of variation within zones supports sampling within zones. In practice, more than one population per zone will therefore have to be identified. The extent of security requirements necessary should be seen in relation to the actual conservation status, the number of zones and their size. In the case of teak in Thailand, 2-3 populations per zone are considered appropriate.

Land tenure and socio-economic conditions will have to be taken into consideration when assessing conservation status. Given the pressure on the teak forest of Northern Thailand, it is planned to place as many conservation units as possible within the Natural Forests or Wildlife Sanctuaries. Even here, socio-economic parameters such as recent development in land use and distance to close villages will be taken into account.

For *in situ* conservation (conservation in natural habitats) the conservation status and the expected long term development shall be taken into consideration. For some stands, it will be necessary to collect fruits and establish *ex situ* conservation stands (plantations at a protected site). These new areas outside the teak forest must be selected where good protection is ensured, and where healthy long term development can be expected. Environmental conditions should be as similar as possible to the original ones. Further, the stands should be regenerated in the future with as little genetic influence from outside as possible.
This requires isolation from pollen and seed. Isolation belts of 300-500 m is generally recommended. Multiple \textit{ex situ} conservation stands can therefore not be located next to each other.

Fifteen candidate areas for conservation of teak in Thailand have been identified based on the above discussion, and by applying the recent survey of the natural teak forest in Thailand (RFD 1994, Mahidol University and RFD 1995). Where possible, areas have been located in already protected areas to assure a good conservation status. The locations are shown in Fig. 3.

An implementation plan for the required conservation activities is proposed by Graudal \textit{et al.} (1999). This implementation plan includes a field survey, and development of management protocols for each stand. Also, conservation measures for each stand should be decided based on the findings of the field survey.

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