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Graudal, Lars; Kjær, Erik Dahl; Suangtho, Verapong; Saardavut, Prasit; Kaosa-ard, Apichart

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CONSERVATION OF GENETIC RESOURCES OF

TEAK (Tectona grandis) IN THAILAND

by

Lars Graudal¹, Erik D. Kjaer¹, Verapong Suangtho², Prasit Saardavut³, Apichart Kaosa-ard⁴

¹Danida Forest Seed Centre · Humlebaek · Denmark
²Forest Genetic Resources Conservation and Management Project (Royal Forest Department/Danish Co-operation for Environment and Development)
³Royal Forest Department · Bangkok · Thailand
⁴Chiang Mai University · Chiang Mai · Thailand

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Publication can be requested from:
Danida Forest Seed Centre
Krogerupvej 21
3050 Humlebaek
Denmark
Tlf: 45-49190500
Fax: 45-49160258
Email: dfsc@sns.dk
Web Site: www.dfsc.dk

Danida Forest Seed Centre (DFSC) is a Danish non-profit institute, which has been working with development and transfer of know-how in management of tree genetic resources since 1969. The development objective of DFSC is to contribute to improve the benefits of growing trees for the well-being of people in developing countries. The programme of DFSC is financed by the Danish Development Assistance (Danida).
PREFACE

Awareness of the importance of conservation at the ecosystem, species and within-species levels has been steadily increasing over the past decades. A number of activities have been initiated furthering conservation and sustainable use of genetic resources. Practical experience, however, has been insufficiently documented, and ‘lessons learned’ from them have been little analysed and only seldom applied on a larger scale. This is especially true in the field of conservation in situ of forest genetic resources.

In 1996 FAO, Danida Forest Seed Centre (DFSC) and a number of national institutions responsible for in situ gene conservation stands of forest tree species in different countries agreed to make a common overall evaluation of a number of in situ conservation areas established in the respective countries in order to learn from the limited practical experience gained. The overall objective of this programme is to provide practical advice and to assist countries in the planning and execution of conservation of genetic resources of forest tree species.

As part of the programme, case studies on the in situ conservation status of a number of important forest species have been prepared in several tropical countries. Although the focus of the studies is on the in situ conservation status, the subsequent planning considers all available conservation measures. In situ conservation is just one method of conserving genetic resources - albeit very often the most important one. Nevertheless, conservation of genetic resources generally requires simultaneous use of several methods.

The present study on teak in Thailand constitutes one of the case studies mentioned. The study has been prepared in collaboration between the Silvicultural Research Division (SRD) of the Royal Forest Department (RFD) in Thailand, the Forest Genetic Resources Conservation and Management Project (FORGENMAP) implemented by RFD with support from the Danish Co-operation for Environment and Development (DANCED), the Forest Resources Division of FAO, and DFSC.

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Danida Forest Seed Centre,
Krogerupvej 21,
DK-3050 Humlebaek, Denmark
Tel: +45 49 19 05 00
Fax: +45 49 16 02 58
E-mail: dfsc@sns.dk
ABSTRACT

The Thai teak forests are under pressure. They have already suffered severely from overexploitation and conversion to agricultural land. Only fragments of the original teak forests remain at present, mainly in a few protected National Parks. Teak is a tree species of major importance for plantings in South East Asia, Africa, South and Central America, and it is therefore considered to be very important to improve the conservation status for the genetic resources in Thailand. A conservation plan for teak in Thailand is developed in the present Technical Note and an implementation plan is outlined.

The ecological conditions vary within teak’s natural distribution area in Thailand. Genetic variation between stands within Thailand is therefore possible. Existing provenance trials support that different Thai provenances may grow differently, which can be the result of adaptation to different environmental conditions, or following thousands of years of separation. It is therefore recommended to conserve a network of conservation stands rather than a few stands. This is also based on theoretical considerations. A number of so-called genecological zones are outlined, and potential gene conservation stands identified in a way that all zones can be represented in the network.

Teak has been planted in Thailand on a large scale since the 1960ies, when a breeding programme was also initiated. Important ex situ resources therefore exist in the clonal collections selected over the last 40 years in superior stands. Also, existing plantations can be important for gene conservation in areas where all the natural teak forests are gone.

Suitable conservation techniques and practical implementation measures are discussed and the required resources are estimated. Similar conservation efforts in other parts of the natural distribution area are highly recommendable.
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1. INTRODUCTION

The purpose of this Technical Note is to identify the requirements for conservation of genetic resources of teak in Thailand, and to present a plan and budget for implementation of the proposed conservation activities.

The note is intended for managers, administrators, planners and researchers involved in the planning and implementation of the specific programme, but may furthermore serve as inspiration to others engaged in or planning similar programmes for other species.

Similar studies have been made for *Pinus merkusii* in Thailand (DFSC/RFD, in press), *Baikiaea plurijuga* in Zambia (DFSC/Zambia FD, in prep.), and *Acacia senegal* in Burkina Faso (DFSC/CNSF, in prep). These studies will also be published as Technical Notes by Danida Forest Seed Centre.

The work constitutes the following steps:

- Description of the background and justification
- Assessment of the conservation status
- Assessment of the genetic variation
- Genecological zonation
- Consideration of the implications of the reproductive biology on the conservation requirements
- Identification of populations to be conserved
- Identification of conservation measures
- Implementation planning and budgeting
- Preparation of management guidelines

General guidelines for planning national programmes for conservation of forest genetic resources are given by Graudal *et al.* (1997)

![Photo 1. Assessment of natural teak trees at Mae Yom National Park, Phrae Province. This is the largest remaining reserve with natural teak forest in Thailand. Photo A.B. Larsen, 1997.](image-url)
2. BACKGROUND AND JUSTIFICATION

Teak (*Tectona grandis*) is a deciduous forest tree species occurring naturally in parts of India, Myanmar, Thailand, Laos and Indonesia (Fig. 1).

The timber is of high value and teak is one of the most important timber species of the world. High quality teak attains prices of several thousand US$ per m$^3$ 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. Teak is easily established in plantations and has been planted in many parts of the tropics. Kjaer & 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. In general teak forests consist of genetically diverse trees, and substantial genetic differentiation between populations - and between single trees within populations - has been found in genetic studies (cf. Keiding *et al.* 1986; Kjaer *et al.*, 1995). Better growth, quality and adaptability can be achieved through careful selection of the best seed sources and trees when raising seedlings for a given planting (cf. Kjaer & Foster, 1996). Genetically broad populations should therefore be maintained as a basis for present and future domestication. Lost diversity means lost options for future use.

Genetic variation is also important for the long-term adaptation of species (Falk & Holsinger, 1991). Populations under stress may respond through natural selection ('survival of the fittest') but only if genetic variance in fitness is present. At the individual tree level, low genetic diversity can lead to inbreeding depression affecting growth, survival and adaptation.

The objectives of conserving the genetic resources of teak are thus to secure the ability of the species to adapt to environmental changes, and to maintain the basis for improving production through future selection and breeding activities. The genetic variation of teak is found among and within geographically separate populations. A number of populations with an appropriate geographic distribution should therefore be protected and managed in order to conserve the genetic variation.

Figure 1. The natural distribution of teak (*Tectona grandis*) (Kaosa-ard 1981, slightly modified according to Champion & Seth 1968 and Keiding *et al.* 1986)
Photo 2. Natural teak forest at Ban Cham Pui, Lampang District. This small forest of less than 20 ha is surrounded by farm land but used to be part of a large area covered by natural teak forest. The forest has been logged several times but still has many teak trees with very good stem form. Teak is dominating with very high crown cover (>80%) at this site, probably due to the human influence. *Xyilia kerrii, Dalbergia sp., Milletia brandisiana* and *Pterocarpus macrocarpus* are major associated species. The forest has now been appointed a gene conservation area. Photo: Kjaer, 1993.
3. THE CONSERVATION STATUS OF TEAK IN THAILAND

Conservation status refers to the present state of the genetic resources and the risk of future erosion. Questions to examine are: Have populations been lost? How well protected are remaining populations? Have remaining populations been subject to genetic erosion? What are the future trends?

The conservation status of a species and its populations can be investigated by looking at its past and present geographical distribution. Prevailing utilisation patterns should be examined by observing changing land use patterns, harvesting of natural forest, planting, introduction of hybridising species and/or provenances, and breeding. Also, occurrence in protected areas is important to consider, because networks of protected areas have fortunately already been established in many countries.

Future trends may be deduced from such information, but may also require consideration of demographic and economic factors, and legislation.

3.1 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 & Seth, 1968), i.e. the lower altitudes which also are the areas most suitable for conversion to permanent agriculture. Also, the fertile luvisols 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.

Thailand’s population increased from about 5.5 in 1850 to 50 million in 1980, while the area under cultivation increased from about 1.5 to nearly 20 million hectares (Meer 1981). The population has today passed 60 million and is expected to reach 70 million by 2020 (RFD, 1996). Suitable land for agriculture has therefore become increasingly scarce, and will be so even more in the future.

Official data report 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 relatively high compared to data from the whole Thai Kingdom, where it has declined from 53% in 1961 to 26% in 1995 (RFD, 1995). Fig. 2 shows the distribution of the mixed deciduous teak forest in Northern Thailand around 1960 as compared to the situation around 1990 (based on RFD 1962, 1983, 1993 and 1995, modified according to RFD 1994; cf. also Collins et al. 1991). The distribution around 1960 is 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. According to official statistics, the total area with natural teak forest in Thailand has been reduced from 65.000 km² in 1960 to 21.000 km² in 1990 (cf. Kjaer & Suangtho 1997). 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 for example estimated to be 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 the northern area.

The traditional shifting cultivation is believed to have further reduced the occurrence of teak in large parts of the remaining deciduous forests, because other species such as Pterocarpus ssp and Xylia ssp are more competitive in invading the swiddens after cultivation due to easier seed dispersal (Mahidol University & RFD, 1995).

3.2 Historic and present use of natural teak forests for timber harvest

Teak has always been an important timber species used by the population of Northern Thailand (Anderson, 1993). Thailand has also been an important supplier of the valuable teak timber to the world market for at least 125 years (De’Ath, 1992). This timber was harvested by selective logging in the natural forests. Sustainable harvest systems were developed based on 20-30 year cutting cycles, but illicit felling was always widespread during the years of logging (Mahidol University & RFD, 1995). Also, encroachment by farmers and conversion to farm land have destroyed the basis for continued logging. A logging ban was imposed in 1989, and since then legal logging can only take place in plantations. Thailand has thus developed from a major teak exporter to a net importer. In 1995, Thailand imported more than 200,000 m³ teak logs or sawn timber (Thaïutsa, 1999).

There are no virgin teak forests left in Thailand. Selective logging has taken place in all native teak forests of Thailand including the now protected areas.
The selective logging may have caused genetic selection towards trees with inferior stem form if only crooked trees have been left for reproduction after logging. However, such genetic effect is only likely in areas where the logging (and negative selection) has been very heavy (see e.g. discussion in Savolainen & Kärkäinen, 1992; and Ledig, 1992).

After the 1989 logging ban, illicit felling has continued (Mahidol University & 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.

Figure 2. Past and present distribution of mixed deciduous forest with teak (Tectona grandis) in Northern Thailand (based on RFD 1962, 1983, 1993, 1994 and 1995).
3.3 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). A comparison of protected areas with the estimated present distribution of teak in Thailand is shown in Fig. 3.

It is seen from Fig. 3 that some of the remaining teak forests are located within protected areas, but also that large tracts are without such protection. Still, small overlaps are found in most parts of teak’s natural Thai distribution.

Mahidol University & RFD (1995) estimate that at present a total of 15 areas with more than 10 km² of mixed deciduous teak forest exists in protected areas, mainly in 7 national parks (Thung Salang Luang, Namtok Chatrakhan, Mae Yom, Phu Miang-Phu Thong, Sri Satchanali, Taksin Maharat, Mae Ping) and one Wildlife Sanctuary (Mae Yuam Fang Khwa). Only Mae Yom National Park includes 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.

![Figure 3.](image-url) Protected areas (Collins et al. 1991) and the natural occurrence of mixed deciduous forest with teak in Thailand (RFD 1983, 1993, 1994 and 1995).
3.4 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 1960s. Major public teak plantation areas in Thailand are shown in Fig. 4. 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 road-sides 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.

Figure 4. Public teak planting areas in Thailand. Each dot represents a teak plantation unit. The public plantation activities have decreased since the beginning of the 1990s, but have in size been replaced by private plantings. Source: Kaosa-ard (1986).
3.5 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 origin of the clones in the Thai breeding programme is summarised in table 1.

Table 1. Origin of trees in the Thai breeding population

<table>
<thead>
<tr>
<th>Origin of selected trees</th>
<th>Number of trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiang Mai</td>
<td>59</td>
</tr>
<tr>
<td>Lampang</td>
<td>139</td>
</tr>
<tr>
<td>Mae Hong Son</td>
<td>34</td>
</tr>
<tr>
<td>Phrae</td>
<td>82</td>
</tr>
<tr>
<td>Sukothai</td>
<td>17</td>
</tr>
<tr>
<td>Tak</td>
<td>2</td>
</tr>
<tr>
<td>Yala</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Teak Improvement Center, Lampang unpublished

The Thai breeding programme is planned to develop into a so-called Multiple Population Breeding (MPB) programme (cf. Namkoong et al. 1980; Wellendorf & Kaosa-ard 1988; Kaosa-ard, 1996). In MPB programmes, the total breeding population (selected clones) is divided into sub-groups. One sub-group may be formed for each specified ecogeographical breeding zone. Alternatively, the sub-groups may reflect different selection criteria.

The strategy allows faster progress and more flexibility in tree improvement (Namkoong et al., 1980, cf. also Barnes, 1984, 1995). The Thai teak breeding population can play an important role in the conservation of teak in Thailand - also in the long term - if the breeding programme evolves into a true MPB programme based on ecogeographical subgroups. Furthermore, future selection and generation turnover should be based on progeny tests in the respective regions. Today, this is not fully the case (Kjaer & Suangtho 1997), but the commercially valuable, selected plus trees in the breeding population still serve as an important ex situ conserved gene pool.

To conclude, the breeding population represents a unique gene pool of trees selected in important parts of the distribution area. There are parts of the distribution area from which only few - or none - plus trees are included, and additional conservation measures are therefore required. Also, at present the breeding population mainly serves as a so-called static conservation measure where no natural selection takes place within the gene pool (the difference between static and evolutionary conservation is discussed in section 8 below).

3.6 The future of the Thai teak forest

It is obvious from the above discussion that the conservation status of the teak forests has decreased over the last decades. However, the political awareness of the importance of the forests has increased in the same period. The Thai government imposed a ban on all commercial logging in natural forests in 1989. This logging ban followed severe flooding in 1988 that was assumed to be partly caused by deforestation on the major watershed areas. Still, the major pressures on the teak forests – conversion to agricultural land – remains unrelieved as the population continues to grow. Also, illegal logging (log poaching) is still a problem after the logging ban (Mahidol University & RFD, 1995) and the loss of the teak forests in terms of both area and quality is therefore likely to continue in the future, although hopefully at decreased pace. The best conservation status is to be expected in natural parks and wildlife sanctuaries – especially where human population density is low, and especially far from existing villages. Reserved forests located close to densely populated areas are under the most severe pressures.
Photo 3. Sak Yai. Large teak tree growing in Nam Pat Forest Park (Uttradit). This tree is considered to be the largest teak tree in the world. Photo: Keiding (1959).

Photo 4. Selected teak ‘plus’ tree near Lampang.

This tree was selected in the early stage of the Thai breeding programme because of its good stem form. It was vegetatively propagated and included in the seed orchards and breeding populations. Today, the Thai breeding population represents a unique gene pool of trees selected in important parts of the distribution area. However, there are parts of the distributional area from which only few - or none - plus trees are included, and additional conservation measures are therefore required. Photo: Keiding, 1965.
4. AVAILABLE INFORMATION ON THE GENETIC VARIATION IN TEAK IN THAILAND

It is important to know the nature of the genetic resource to be conserved, especially how much the various Thai teak populations differ genetically. Should only one, a few, or many populations be conserved in order to safeguard the genetic resource? In principle, all major gene pools should be conserved, but the number of conservation stands should on the other hand be limited to a manageable level. Reliable information on the distribution of genetic variation - within and between geographic regions - is 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, study variation in biochemical and molecular markers in the laboratory, and to some extent to predict possible genetic variation patterns from ecogeographic variation. In Thailand, data is mainly available from field trials, but results from biochemical markers will also become available within the next years. The utilisation of this information is discussed below.

4.1 Field trials

Study of metric characters or adaptive traits in field trials was earlier the dominating technique and it is still today the most robust and valid way of assessing genetic variation in these characters. In field trials, the performance of different populations is assessed under conditions close to the conditions under which the trees grow in plantations. Information from such experiments is very valuable, because assessed adaptive genetic variation is still the best basis for conservation activities (Eriksson, 1995).

Field trials are the most direct way to estimate the potential of different seed sources, but a few important limitations must be considered (cf. Kjaer 1997):

- The result from a given trial (or set of trials) reflects growth under the given conditions. Tests on other sites may result in different patterns. Further, if climatic extremes had appeared during the testing period it might have changed the results. Also, trials are often evaluated at a young age and new genetic patterns may be revealed, as the trees grow older.
- Field trials often include seedlots collected from both natural populations and from planted stands.

However, comparison of seedlots from natural populations with seedlots from planted stands may not be fully valid. Family structure in natural populations will be associated with a varying degree of inbreeding depression. This can favour the progenies from plantations relative to natural populations, especially when evaluated for vigour. Observed variation between populations within - or between - geographic regions may therefore be caused by differences in inbreeding coefficient, rather than true genetic differentiation. Important gene pools in natural populations may be underrated compared to plantations. This can mislead conservation efforts, because family structure is easily broken down (e.g. when seed production areas are established).

• Most provenance trials are based on only one year of seed collection from each population. However, the collection may not be fully representative, and several studies have furthermore suggested that climatic conditions during meiosis and fertilisation influence the subsequent performance of the progeny - at least for some species (Skrøppa & Johnsen, 1994). Other collections may therefore yield different results.

The point is that observed differences between a set of seed sources may therefore actually be determined with lower accuracy than normally considered. This is true even if the experimental errors in the field trials are small.

Three provenance trials of teak exist in Thailand. Two of these include several Thai provenances, and can therefore be used to infer on the pattern of variation within Thai teak. A larger number of trials were established, but have subsequently been lost due to fire or other factors. At present, information can thus only be obtained from these two sites. The information that these two trials contribute to the understanding of genetic variation of teak in Thailand, is discussed briefly in Annex 1. In conclusion, the provenance trials suggest that genetic differentiation 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 is found between sources within provinces.

4.2 Genetic markers

Biochemical and molecular markers can be used for fast surveys of genetic variation within and between populations (see e.g. Fig. 5). The genetic markers are normally considered not to be influenced by natural selection. Important genetic differentiation fol-
lowing divergent natural selection in a few genera-
tions may therefore not be detected by the markers. 
This is supported by the fact that several studies of
forest trees, including teak, have shown larger dif-
ferentiation between adaptive traits than between bio-
chemical markers (Karku et al. 1996; Kjaer et al. 
1996). This is a serious drawback with the use of 
genetic markers (Eriksson, 1995). Still, genetic 
markers can contribute important information on 
migration routes, hybridisation, and breeding sys-
tems.

Only a few populations have been examined with al-
lozymes (Kjaer et al., 1997). However, a study of 
variation in genetic markers on a large number of 
populations in Thailand will soon be finalised 
(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 con-
servation plan when it has been analysed.

4.3 Ecogeographical variation

A study of clinal variation in ecological parameters 
within the species’ distributional range provides 
knowledge of the ecogeographical variation of the 
species. It is generally assumed that similarity of 
ecological conditions implies similarity of genetic 
constitution. An ecogeographic survey will therefore 
also provide a first indication of possible genetic var-
ation. Ecogeographic surveys can be used for sev-
eral purposes. In forestry it has primarily been used 
to define tree seed zones with specific recommenda-
tions for seed collection and utilisation of seed 
resources.

The natural vegetation of Thailand has been sur-
veyed and mapped several times (Ogawa et al. 
1961; RFD 1962, 1983, 1993 and 1995, anony-
mous 1971; cf. also Smitinand 1977, Collins et al. 
1991 and Boontawee et al. 1995). Good topograph-
ic maps exist (Royal Thai Survey Department 1978-
95; cf. also Mahapol 1954 and Werner 1993), cli-
matic data is available (Meteorological Department, 
Prime Ministers Office; cf. also FAO 1987, Kaosa-
ard 1983, Eis 1986), soils have been surveyed and 
seed zone systems constructed.

A general seed zone system for Thailand prepared 
by Eis (1986) is shown in Fig. 6. This zonation is 
based on topography, precipitation (amount and dis-
tribution) and temperature. A climatic seed zone 
system specifically for teak based on temperature 
and precipitation has been constructed by Kaosa-
ard (1983), and is shown in Fig. 7.
Figure 5.
Example of an allozyme pattern of 11 teak trees (GOT locus). Allozymes can be used for fast surveys of genetic variation within and between populations. Important genetic differentiation may not be revealed by allozymes, but the markers can give important information on e.g. breeding systems, gene flow and migration routes. Photo: Kjaer, 1993.

Figure 6.
General seed zone system fra Thailand. Only northern parts shown. Source: Eis (1896)

Figure 7.
5. 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).

Genecological zonation is a practical tool for identification of conservation requirements. It consists in identifying areas with uniform ecological conditions, subject to none or limited gene flow from surrounding areas. Factors used for zonation should reflect, directly or indirectly, divergent natural selective forces. Genetic races may e.g. have developed, if a species grows 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 in 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.

Genecological zonation should ideally be specific for individual species, or at least for major groups of species. Species may have different reproduction biology, react differently to environmental clines or heterogeneity, and they may reflect entirely different life histories in terms of migration, hybridisation events, or human utilisation. For economic reasons - and due to lack of species specific data - specific systems will in general be constructed for species of major importance, only. Teak is one such species. The genecological zones for teak can be outlined by combining the data from the field trials and the available data on ecogeographic variation, as will be discussed below.

5.1 Information from patterns of natural vegetation in Northern Thailand

The natural vegetation reflects the combined effect of the most important ecological factors. Knowledge of natural vegetation types, often mapped, is therefore a good starting point. A vegetation map of Thailand is shown in Fig. 8 (cf section 4.3).

The vegetation of Northern Thailand has been influenced by man, and the occurrence of teak is believed to have been influenced by traditional shifting cultivation as mentioned above. Natural vegetation types may therefore not be truly known. Also, it is well established that teak has developed significantly different races (Keiding et al. 1986; Kjaer et al. 1995) - probably partly as a result of adaptation to different ecological conditions within its large distribution area. The distribution area of the species does therefore per se reflect the information necessary to infer on the likely genetic patterns. The variation in a number of specific ecological factors within the distribution area of teak in Thailand must therefore be considered.
Figure 8. The vegetation types of Thailand. The vegetation of Thailand has been mapped several times (Ogawa et al. 1961; RFD 1962, 1983, 1993 and 1995; anonymous 1971). Here reproduced after anonymous 1971.
5.2 Physiographical regions, and mountain ridges as barriers to gene flow

Mooremann and Rojanasoonthon (1968, 1972) have divided Thailand into six physiographical regions, which are shown in Fig. 9.

Comparing Fig. 9 with the natural distribution of teak in Fig. 1, shows that teak primarily occurs in the North and West Continental Highlands and in the Central Highlands. It used to grow also in northern parts of the Central Plain, but here it has been cleared to open up for agriculture.

The major topographical features of Northern Thailand are shown in Fig. 10 (Mahapol 1954, Royal Thai Survey Department 1978-1995, hereafter Werner 1993).

Teak is not found above 900 meters’ altitude, and many north-south heading mountain ridges therefore create north-south heading gaps in the natural distribution of teak in parts of Northern Thailand (compare Fig. 2 and Fig. 10). These gaps may constitute barriers to gene flow between east and west and would thus result in separate eastern and western genecological zones (which is supported by the observation from field trials as discussed in section 4.1). The question is how many zones should be formed? Eis (1986) has identified two. The topographical features in Fig. 10 could indicate six. The provenance clustering in the trial shown in Annex 1, Fig. 14, would seem to speak in favour of at least three.

5.3 Zonation based on precipitation, temperature and soils

Kaosa-ard (1983) used the ratio between annual precipitation and average temperature to construct the climatic tree seed zones shown in Fig. 7 above. The zones created this way are based on climatic gradients and the borders are somewhat arbitrary. It is, however, seen that zone IV and the southeastern part of zone III according to Kaosa-ard correspond to zone 1 and 6 according to Eis, respectively. Zone III according to Kaosa-ard is composed of three climatically similar but geographically separate areas. This may be acceptable from a utilisation perspective where deployment of provenances is concerned with matching seed source to planting site. The geographic separation may, however, constitute a barrier to gene flow and from a conservation point of view, such areas should be considered as different genecological zones because the populations may have developed into genetically different races.

Variation in soil characteristics may cause pronounced differences in vegetation within areas of similar topography and climate. Over limited distances, such variation will not function as a barrier against gene flow within the same species, as long as the distribution is continuous. Preferred soils of teak are described by Mahapol (1954). Although teak grows from low alluvial flats to precipitous slopes, it favours light well-drained porous soils, loam and sandy loam being most preferable. It detests ‘wet feet’ avoiding stiff clayey soil and waterlogged areas, and will not thrive on lateritic or too dry sandy soils. The soils of Thailand have been described by Moormann and Rojanasoonthon (1968, 1972). Their work has been used for the preparation of the FAO-Unesco Soil Map of the World (FAO-Unesco 1979). The part of this map covering Thailand is shown in Fig. 11. Gleyic Luvisols (Lg; poorly drained, but quite fertile soils) are widely occurring in the important Ping and Yom basins that (used to) carry mixed deciduous forest with teak. Chromatic Luvisols (Lc) with better drainage cover smaller, patchy areas very suitable for teak (but also agriculture). Less fertile soils also occur in the natural teak region, although these soils often carry dry dipterocarp forest.

The soils often vary within small distances. Soil characteristics are therefore less feasible to use for genecological zonation, because often gene flow is expected to counteract local adaptation. Variation in soil characteristics within zones may however be used to guide sampling among populations within zones.
Figure 10.
Major topographical features of Northern Thailand (Werner 1993).

Figure 11.
Soil map of Thailand (FAO-Unesco 1979).
5.4 Five geneecological zones for the remaining natural teak in Thailand

Based on the examination of topography, climate and vegetation, a total of five geneecological zones was drawn. The result is shown in Fig. 12.

Considering the effect of altitude on distribution, mountain ridges above 900 m were used as main boundaries. Zone I was separated based on the topographical features and the climate (corresponding very closely to zone 6 of Eis). The central part of the distribution area of teak was divided into three zones, II, IV and V, based on topography. Finally the northernmost part was separated due to the moist climate and the very scattered occurrence of teak in that area. All boundaries were drawn so that separation of continuous forest areas were avoided.

Geneecological 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 (section 4.2) may be of particular value for such revision.

Figure 12. Preliminary geneecological zones GI - GV for teak in Thailand. Colours correspond to the Kaosa-ard (1983) seed zones.
6. THE REPRODUCTIVE BIOLOGY OF TEAK

For safe conservation, it is important to know the species reproductive biology. Some species depend on specific pollinators (insects, birds or bats), and successful regeneration will then depend on availability of pollinators. Also, genetic patterns can be influenced by the reproductive system (Hamrick et al. 1992) and may thus influence the geneecological zonation. The reproductive biology of Tectona grandis has furthermore attracted special attention, because low fruit production causes problems in supply of genetically good tree seed (see e.g. Kaosa-ard et al. 1998).

Flowers of teak in Thailand are mainly visited by small insects of which many only work within the crown (e.g. ants and small bees, Bryndum & Hedegaard 1969; and Hedegaard 1973). Many seltings are therefore to be expected, because selfing pollen is almost as effective as outcrossing pollen in fertilising the flowers (Tangmitcharoen & Owens, 1996). However, the resulting teak fruits are almost entirely outcrossed under natural conditions (Kjaer & Suangtho, 1995; Kertidakara & Prat, 1995). The low seed yield may therefore be a result of a high degree of seltings followed by strong selection against inbred embryos during seed development, resulting in a low seed yield with predominantly outcrossed progenies (Kjaer, 1997). This hypothesis is supported by observations by Palupi & Owens (1996) that the majority of selfed embryos abort soon after fertilisation and therefore never develop into mature seed.

Low seed yield per tree means that most existing plantations probably are based on seed collected from many trees. There may be exceptions. It is, for example, assumed that large exotic plantations in parts of Central America originate from seeds collected from few trees (Keogh 1980, Kjaer & Siegismund, 1995). Teak is exotic to Central America, and the ‘genetic bottleneck’ is here due to the introduction history. A few trees were initially raised in botanical gardens and subsequently used for smaller plantations, which in turn became important seed sources. Similar life histories are less likely in Thailand where teak occurs naturally, but large-scale seed collections from relatively few trees along roadsides and in Temples have been reported.

The reproductive studies suggest that severe inbreeding depression in seed-setting capacity may follow as a result of selfing or crossing between related trees.

Photo 5.
Ant visiting a teak flower.
The flowers of teak in Thailand are visited by many small insects that can promote selfing. This may partly explain the low reproductive success.
Photo: Keiding.
7. A NETWORK OF TEAK CONSERVATION POPULATIONS IN THAILAND

The gene resource conservation areas should be identified in a way that (Graudal et al. 1997):

- secures representation in all geneecological zones
- includes areas where the presence of teak is verified by the most recent surveys available
- gives preference to already protected areas

The final selection of areas will have to be based on field survey. Criteria for final selection will be:

- Conservation status
- Size (number of mature trees)
- Management options
- Costs of protection and management

These important decision parameters are discussed below. Conservation status and population size are described in this section. Management options and costs of protection are dealt with in section 8 and 9.

Comparing the geographical distribution of teak with the geneecological zones provides the over-all framework for sampling of conservation populations. To cover the geneecological 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 (discussed in section 4 above) 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.

7.1 Taking conservation status into account

Land tenure and socio-economic conditions will have to be taken into consideration when conservation status is assessed. 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 nearby villages will be taken into account.

For in situ conservation (conservation in natural habitats), site conditions are given, but the conservation status and the expected long-term development shall be taken into consideration. New areas outside the teak forest selected for establishment of ex situ stands must ensure good protection as well as healthy long-term development. Environmental conditions should be as similar as possible to the original ones.

The conservation 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 are generally recommended. Consideration for isolation can therefore become an important parameter when final conservation units are selected.

7.2 Required size of the conservation populations

Genetic variation is lost relatively fast in small populations. Also, inbreeding will build up in small, isolated populations, which can cause reduced fitness. Therefore, the conservation stands should not be too small. Based on population genetic considerations, some guidelines concerning size can be issued as discussed below (cf. Kjaer & Graudal, in prep.):

In situ stands

As a rule of thumb, an in situ conservation stand should initially consist of at least 150, and preferably more than 500 interbreeding individuals of the species to be conserved. The stand should be gradually increased so that the final stand preferably holds 500-1500 individuals (Graudal et al. 1997). For teak, the recommendable population size may be somewhat larger, because of the low seed production of the trees.

The density of teak in the Mae Yom National Park has been surveyed intensively, and approximately 35 reproductive trees, diameter at breast height (DBH) >10 cm, are found per ha in the areas where teak is most dense (Mahidol University & RFD, 1995; see table 2). Core conservation areas of 50-100 ha are therefore in principle enough in order to obtain 1500-3000 mature teak trees. The density differs between areas and stands. Only 16 trees with DBH >10 cm were, for example, found per ha in an assessment in Mae Hong Son (Mahidol University and RFD, 1995; see table 2). The density in each conservation unit should therefore be determined by field surveys. The density of reproductive teak trees may be much lower in the areas close to the southern limits of its natural distribution, where only scattered teak occurs.
Table 2. Recorded density of reproductive teak trees in natural teak stands sampled in different provinces. Source: Mahidol University & RFD, 1995.

<table>
<thead>
<tr>
<th>Area</th>
<th>No. of plots</th>
<th>Trees/ha DBH &gt; 10 cm</th>
<th>Trees/ha DBH &gt; 30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mae Yom (high density teak part)</td>
<td>Intensive sampling</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
<td>Tak</td>
<td>144</td>
<td>56</td>
<td>44</td>
</tr>
<tr>
<td>Lampang</td>
<td>36</td>
<td>70</td>
<td>33</td>
</tr>
<tr>
<td>Kamphaengphet</td>
<td>144</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Mae Hong Son</td>
<td>108</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Chaing Mai</td>
<td>36</td>
<td>60</td>
<td>33</td>
</tr>
<tr>
<td>Mai Ping</td>
<td>252</td>
<td>26</td>
<td>13</td>
</tr>
</tbody>
</table>

In practice, larger areas than strictly required from genetic considerations may be protected in order to assure an appropriate reproduction unit. Also, the conservation populations should constitute a suitable management unit.

Selection of seed for ex situ conservation

For ex situ conservation, it is important to collect from a sufficient number of trees in the threatened population in order to get a good sample of the genetic diversity at the given site. Collections from few trees will also result in related progenies (half sib families), which can cause inbreeding problems later on.

As a rule of thumb, ex situ conservation from large populations should not be based on seed collected from less than 25 randomly chosen and supposedly unrelated individuals, mixed in approximately equal proportions. Teak seed is normally collected from the ground under the trees, and collection from many trees will often be easy and is therefore recommended.

If only few trees are left (e.g., < 200 reproductive trees), seed should be collected from all trees. In such cases, the seed should be collected from each tree in separate bags, and afterwards mixed in approximately equal proportions. This will reduce the risk that a few trees have contributed with the majority of the seed to the progeny. Often, trees with very little seed are included in the collection, and it will therefore not be possible to mix in exactly equal amounts because the total amount of seed will then be very limited. The effect of unequal seed contribution should then be monitored by calculating the so-called effective number. The effective number \( N_e \) is calculated from the percentage \( p_i \) of seed that each contributes to the total seedlot:

\[
N_e = 1 / \sum p_i^2
\]

For example: assume for the purpose of illustration that 100 kg seed are collected under 50 trees for ex situ conservation of an endangered stand. The contribution of the single trees (kg fruits, here = % of total collection) is listed in table 3. With the given data \( \Sigma p_i^2 = 0.09^2 + 0.08^2 + ... + 0.0001^2 + 0.0001^2 = 0.0443 \), the effective number will be \( N_e = 1 / \Sigma p_i^2 = 1 / 0.0443 = 23 \). The effective number is thus only 23, although seed was collected from 50 trees.

The effective number calculated this way should preferably not be less than 50, and effective numbers above 100 are to be preferred.

\( N_e \) can be increased by restricting the contribution of some of the most fertile trees. In the example above, \( N_e \) calculated as above can be increased from 22 to approximately 35, if only 2 kg are included from tree 1-19 (calculations not shown). The seed available for establishment of the ex situ stand will, of course, be reduced when parts of the seed from the fertile clones are discarded, in this case from 100 kg to 56 kg. This amount will probably still be sufficient to establish an ex situ conservation stand, but only if careful nursery practices are applied, including seed pre-treatment. Still, an effective number of 35 is at the lower end.

The calculation of \( N_e \) becomes more complicated when effect of pollen contribution is taken into account (see e.g. Kjaer, 1996).

In some cases, it may be difficult to find stands where it is possible to obtain the recommended \( N_e > 50 \). Mixing seeds from several small stands in a homogeneous region will then be an important option.
When *ex situ* conservation stands of teak are established, the aim should be a final stand size of no less than 1500 trees at generation turnover. If it is assumed that 100 mature teak trees are maintained per ha at rotation age, this means that the conservation plantings should be at least 15 ha (100 rai). With 2,000 seedlings planted per ha, this means that 30,000 seedlings should be raised in the nursery. This amount of seedlings may not always be available, and larger spacing should then be considered.

### 7.3. Candidate areas for conservation of teak in Thailand

Fifteen candidate areas for conservation of teak in Thailand (table 4) 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 & RFD 1995). Where possible, areas have been located in already protected areas to assure a good conservation status. The locations are shown in Fig. 13. The selection of these areas will be verified through field observations (cf. section 9).

#### Table 3. Calculation of effective population number in a seed collection for ex situ conservation (based on a fictive example)

<table>
<thead>
<tr>
<th>Tree no. (i)</th>
<th>Kg seed</th>
<th>p(i)</th>
<th>p(i)^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.000</td>
<td>0.090</td>
<td>0.008</td>
</tr>
<tr>
<td>2</td>
<td>8.000</td>
<td>0.080</td>
<td>0.006</td>
</tr>
<tr>
<td>3</td>
<td>7.000</td>
<td>0.070</td>
<td>0.005</td>
</tr>
<tr>
<td>4</td>
<td>5.000</td>
<td>0.050</td>
<td>0.003</td>
</tr>
<tr>
<td>5</td>
<td>5.000</td>
<td>0.050</td>
<td>0.003</td>
</tr>
<tr>
<td>6</td>
<td>4.500</td>
<td>0.045</td>
<td>0.002</td>
</tr>
<tr>
<td>7</td>
<td>4.500</td>
<td>0.045</td>
<td>0.002</td>
</tr>
<tr>
<td>8</td>
<td>4.200</td>
<td>0.042</td>
<td>0.002</td>
</tr>
<tr>
<td>9</td>
<td>4.100</td>
<td>0.041</td>
<td>0.002</td>
</tr>
<tr>
<td>10</td>
<td>4.000</td>
<td>0.040</td>
<td>0.002</td>
</tr>
<tr>
<td>11</td>
<td>3.800</td>
<td>0.038</td>
<td>0.001</td>
</tr>
<tr>
<td>12</td>
<td>3.700</td>
<td>0.037</td>
<td>0.001</td>
</tr>
<tr>
<td>13</td>
<td>3.400</td>
<td>0.034</td>
<td>0.001</td>
</tr>
<tr>
<td>14</td>
<td>3.100</td>
<td>0.031</td>
<td>0.001</td>
</tr>
<tr>
<td>15</td>
<td>2.900</td>
<td>0.029</td>
<td>0.001</td>
</tr>
<tr>
<td>16</td>
<td>2.700</td>
<td>0.027</td>
<td>0.001</td>
</tr>
<tr>
<td>17</td>
<td>2.400</td>
<td>0.024</td>
<td>0.001</td>
</tr>
<tr>
<td>18</td>
<td>2.200</td>
<td>0.022</td>
<td>0.000</td>
</tr>
<tr>
<td>19</td>
<td>2.000</td>
<td>0.020</td>
<td>0.000</td>
</tr>
<tr>
<td>20</td>
<td>1.800</td>
<td>0.018</td>
<td>0.000</td>
</tr>
<tr>
<td>21</td>
<td>1.700</td>
<td>0.017</td>
<td>0.000</td>
</tr>
<tr>
<td>22</td>
<td>1.700</td>
<td>0.017</td>
<td>0.000</td>
</tr>
<tr>
<td>23</td>
<td>1.600</td>
<td>0.016</td>
<td>0.000</td>
</tr>
<tr>
<td>24</td>
<td>1.500</td>
<td>0.015</td>
<td>0.000</td>
</tr>
<tr>
<td>25</td>
<td>1.500</td>
<td>0.015</td>
<td>0.000</td>
</tr>
<tr>
<td>26</td>
<td>1.200</td>
<td>0.012</td>
<td>0.000</td>
</tr>
<tr>
<td>27</td>
<td>1.000</td>
<td>0.010</td>
<td>0.000</td>
</tr>
<tr>
<td>28</td>
<td>0.700</td>
<td>0.007</td>
<td>0.000</td>
</tr>
<tr>
<td>29</td>
<td>0.600</td>
<td>0.006</td>
<td>0.000</td>
</tr>
<tr>
<td>30</td>
<td>0.500</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>31</td>
<td>0.500</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>32</td>
<td>0.500</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>33</td>
<td>0.500</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>34</td>
<td>0.500</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>35</td>
<td>0.500</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>36</td>
<td>0.480</td>
<td>0.005</td>
<td>0.000</td>
</tr>
<tr>
<td>37</td>
<td>0.410</td>
<td>0.004</td>
<td>0.000</td>
</tr>
<tr>
<td>38</td>
<td>0.320</td>
<td>0.003</td>
<td>0.000</td>
</tr>
<tr>
<td>39</td>
<td>0.250</td>
<td>0.003</td>
<td>0.000</td>
</tr>
<tr>
<td>40</td>
<td>0.170</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>41</td>
<td>0.150</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>42</td>
<td>0.100</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>43</td>
<td>0.080</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>44</td>
<td>0.060</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>45</td>
<td>0.050</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>46</td>
<td>0.050</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>47</td>
<td>0.050</td>
<td>0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>48</td>
<td>0.010</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>49</td>
<td>0.010</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>50</td>
<td>0.010</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The table assumes that 100 kg seed were collected under 50 trees for *ex situ* conservation of an endangered stand. The relative contribution from the single trees is listed above.

The total amount of seed (Σ seed) is = 9 + 8 + ... + 0.01 + 0.01 = 100 kg in this example. The relative contribution p(i) (3rd column) varies from 0.09 to 0.0001. The sum of squared ‘p’s (4th column) can be calculated:

\[ \sum p_i^2 = 0.09^2 + 0.08^2 + ... + 0.0001^2 + 0.0001^2 = 0.043 \]

The effective population number is then estimated to

\[ N_e = \frac{1}{\sum p_i^2} = \frac{1}{0.043} = 23 \]
Figure 13. Areas tentatively identified for conservation of the genetic resources of teak in Thailand (cf. Also table 4).
8. IDENTIFICATION OF CONSERVATION MEASURES

Different conservation methods can be used when the targeted gene pools have been identified. The genetic patterns of variation can be maintained in either evolutionary or static populations, and either in situ in their natural habitats or ex situ in planted stands. These options are discussed below, and conservation measures for the identified teak conservation populations are suggested.

8.1 Evolutionary and static conservation measures

The preferred approach to conservation of genetic resources in forestry is normally to maintain evolutionary conservation populations (opposite to static conservation) in the form of living stands, preferably in situ, but also ex situ (Graudal et al. 1997). In such populations, the genetic composition is allowed to adapt to the prevailing environmental conditions - and their change with time. Climatic changes at a given site may thus be responded to by natural selection in favour of the fittest trees under the new conditions. This will support adaptation of the local conservation populations to the new conditions.

Static conservation maintains specific genetic compositions, e.g. by long term storage of seed in gene banks or vegetatively propagated clones in clonal collections. Well-defined genetic material can thus be conserved with their present genetic composition, as no changes - in principle - should take place during the static conservation. In Thailand, the teak breeding population represents such a static conservation population (cf. table 1 and photo 6).

8.2 Conservation in situ and ex situ

Conservation of genetic resources often requires simultaneous use of several methods. In situ is often preferred because it allows continued interaction with other species. However, when security is evaluated, establishment of planting ex situ on protected areas with seedlings propagated from a threatened population, will often be recommendable as a supplement to the in situ conservation network.

Ex situ conservation of seeds in gene banks is often recognised to be an important complement, but the rapid decrease of germination capacity of teak seeds (see e.g. Suangtho, 1980) makes ex situ storage in seed banks less feasible for teak.

8.3 Suggested conservation measures for the identified teak conservation populations

The proposed conservation measures for fifteen areas identified are listed in table 4.

It is seen that establishment of in situ conservation stands is generally preferred in all genecological zones. The selected areas at Mae Yom in zone G V will, however, be prone to flooding due to planned dam building. Establishment of ex situ stands with this material may therefore be relevant. For areas still to be surveyed, ex situ conservation will have to be considered, in particular for stands outside protected areas, where the conservation status may be low (cf. section 3).
Table 4. Measures proposed/considered for the conservation of the genetic resources of teak in the areas tentatively identified in Thailand

<table>
<thead>
<tr>
<th>Location</th>
<th>Area (ha)</th>
<th>Geneecological zone</th>
<th>Conservation measures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Existing in situ conservation areas</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Ban Cham Pui</td>
<td>20</td>
<td>G IV</td>
<td>in situ</td>
</tr>
<tr>
<td>2. Mae Yom National Park</td>
<td>6400</td>
<td>G V</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td><strong>Proposed new conservation areas</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Mae Ping National Park</td>
<td>1000</td>
<td>G IV</td>
<td>in situ</td>
</tr>
<tr>
<td>4. Huay Mae Salab Reserved Forest</td>
<td>*</td>
<td>G II</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>5. Umphang Wildlife Sanctuary</td>
<td>*</td>
<td>G I</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>6. Pong Salee Botanical Garden</td>
<td>100</td>
<td>G III</td>
<td></td>
</tr>
<tr>
<td>7. Huay Mae Wang Chan</td>
<td>500</td>
<td>G I</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>8. Mae Chaem (Doi Cha Ko Huay Ha)</td>
<td>200</td>
<td>G II</td>
<td>in situ</td>
</tr>
<tr>
<td>9. Huay Mae Lao, Ciang Khong</td>
<td>*</td>
<td>G V</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>11. Doi Chiang Dao</td>
<td>*</td>
<td>G III</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>12. Nam Pat Forest Park</td>
<td>20</td>
<td>G V</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>13. Si Nakarin, Kanchanaburi</td>
<td>*</td>
<td>G I</td>
<td>in situ/ex situ</td>
</tr>
<tr>
<td>14. Tha Song Yang</td>
<td>*</td>
<td>G II</td>
<td>in situ/ex situ</td>
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<tr>
<td>15. Klong Wan Chao</td>
<td>*</td>
<td>G I</td>
<td>in situ/ex situ</td>
</tr>
</tbody>
</table>

Note: cf. Fig. 13. * indicates areas to be surveyed.

Photo 6. Clonal archives at Mae Gar. Graftings of the selected trees in the Thai breeding programme are growing in this and other clonal archives. Photo: Keiding, 1989.
9. IMPLEMENTATION OF CONSERVATION ACTIVITIES.
PLANS AND BUDGETS

Implementation of the conservation plan comprises a number of activities including:

1. Long-term planning of activities. Reporting, and budgeting
2. Preparation of annual work plans
3. Field survey of the tentatively identified areas: final selection of the populations to be conserved
4. Decision of conservation measures to be taken (in situ or ex situ)
5. Demarcation and protection of in situ stands
6. Sampling and seed collection in populations for ex situ conservation
7. Establishment of ex situ conservation stands
8. Management of conservation stands
   - Management guidelines
   - Protection
   - Monitoring (inspect and assess)
   - Tending

The activities are partly overlapping and some will reoccur at different intervals. An implementation schedule is shown in table 5.

The budget for the long-term implementation schedule is included (Annex 2). The long-term plan and budget are based on the demarcation and establishment of 15 in situ conservation stands and 4 ex situ conservation stands. Four of the fifteen tentatively identified sites are located outside protected areas and it may therefore be required to ‘replicate’ at least four of the natural stands ex situ at an early phase. The first revision of implementation schedule and budget should be made after the field survey has taken place and the specific conservation measures have been identified.

9.1 Field survey

A field survey is required, and it should result in the final selection of populations to be conserved and the conservation measures to apply (in situ and/or ex situ). The field survey will involve inspection of the 15 sites and an assessment of the selection criteria described in section 7. The inspection of potential in situ conservation stands involves i.a. mapping and preparation of reporting protocols. Methods for more thorough assessments are in preparation (DFSC, in prep.).

9.2 Management of in situ stands

In situ stands should be demarcated and protected. Signboards (metal plate with map and key figures) should be put up. Stands in protected areas (National parks, Botanical gardens, Wildlife Sanctuaries) are generally considered sufficiently secured, but their conservation status should be evaluated in each case. Other stands (e.g. in Reserved Forests) may need to be replicated ex situ. Fire control is in general not required, but prescribed burning may be necessary.

Monitoring will consist of regular annual inspections, and less frequent more thorough assessments. Annual inspections may be done by the local management offices of the authority locally responsible as part of their ordinary services. A standard format for annual reporting to RFD will be required. Each stand should be assessed by RFD every fifth year. This would mean assessment of 2-3 stands/year.

Assessment of selected areas has already been undertaken (Mahidol University & RFD 1995; and DFSC/RFD 1998). These assessments will contribute to the development of practical management guidelines for the conservation areas.

Most important is probably that management of the conservation stands is based on a participatory approach. Experience from other conservation programmes show that conservation without local participation is not a sustainable strategy in densely populated areas (Granhof, 1998; DFSC/RFD, in press).
Table 5. Long-term implementation schedule for activities for conservation of the genetic resources of teak in Thailand.

<table>
<thead>
<tr>
<th>Activity</th>
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</table>

9.3 Establishment and management of ex situ stands

Selected conservation areas with low conservation status have to be replicated ex situ. Their status and the need of such additional protection will be assessed during the field surveys. Seed collection should follow the overall guidelines given in section 7. The ex situ stands being established should consist of 1500 individuals at rotation age, i.e. 15 ha per stand or approximately 100 rai per stand.

Monitoring of ex situ stands is in principle the same as for the in situ areas. In practice there are, however, important differences. The ex situ stands will in general be located on secure sites (cf. section 7 above). Fencing around the stand using concrete posts stretched with barbed wire may be necessary as in plantations. The stands are planted and will thus require general plantation management. Tending during the first five years will consist of weeding, fertilisation and fire control. The first thinning is expected to take place 10 years after establishment. The status of the ex situ stands will also have to be regularly assessed. General guidelines for assessment of ex situ conservation stands are given by Graudal (1996).

9.4 Preparation of management guidelines

To assure a good conservation status of the conservation stands, they should be managed and monitored for the specific purpose of conserving the genetic resources. Preparation of management guidelines for conservation stands is dealt with in more detail by Graudal et al. (1997). As mentioned in the preface, DFSC is, in collaboration with FAO and several national institutions, in the process of compiling practical experience from conservation efforts in different tropical countries. The amount of practical experience is limited, and the situation will of course be unique for each species and country.
When tending is required, it should favour stability and regeneration. For some populations the conservation effort will consist of a certain management system, which may include e.g. cutting of competitive species, and control of animal grazing or fire. Thinning is generally considered the most important tending intervention, in particular where it stimulates regeneration. In pure stands (ex situ) where evolutionary conservation is the purpose, thinning should in principle support naturally selective forces and may therefore not be purely systematic. In mixed stands (in situ), thinning and regulation of species composition should be undertaken with much caution as it may interfere with yet unknown reproduction patterns (e.g. animal pollination).

In some cases, the conservation effort can be combined with different forms of forest utilisation, if the use does not change the genetic constitution of the stands markedly. In some cases, conservation may be combined with ordinary forest management. For teak in northern Thailand, the majority of the in situ populations will be placed in the protected area where no utilisation of forest products will be allowed.

In some cases enrichment planting can be considered. In such cases the seedlings should be raised from seed collected locally.

Based on results from the field survey, practical management guidelines for each population will be issued.

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ANNEX 1

Teak provenance trials in Thailand: Variation between thai populations

The international trial at Pha Nok Khao

Six Thai provenance trials are included in an international provenance trial at Pha Nok Khao, Khaen Khan province. Results in terms of both survival, vigour, stem form, 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 Kaosaard (1996). 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).

The number of Thai provenances included is fairly low, and the amount of information on the genetic variation of teak in Thailand that can be deduced is therefore limited. The results are presented in terms of a so-called distance tree in Fig. 14. Short distance between two provenances in the ‘tree’ implies similarity in performance in the trial at Pha Nok Khao.

The origin of the tested six Thai and one Laos (natural) provenances is plotted on a map of Northern Thailand in Fig. 15. It is seen that the result of the multivariate analysis shows a tendency to differences between eastern and western provenances.

Figure 14. Least square distance tree of provenances in the international provenance trial in Pha Nok Kao. Six Thai and three Laotian provenances are included (marked with asterisk). Based on Mahalanobians distances (slightly modified after Kjaer et al. 1996).
The Trial at Huey Tak

A number of national provenance trials have been established in Thailand. Of these only one, the Huey Tak trial, was successful in the sense that it could be assessed and analysed. Even this trial has suffered from problems with fire in the initial stage. The provenance trial comprising 30 Thai provenances was established in 1966 at Huey Tak, near Ngao, Lampang Province. The geographic representation of Thai provenances in this trial is very good compared to the trial in Pha Nok Khao. 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 the Huey Tak analysis is low compared to the observations from the international trial at Pha Nok Khao. Also, the environmental heterogeneity has been relatively large in Huey Tak. Still, important information can be gained from this trial in relation to conservation (Kjaer, 1999):

- Significant differences are found 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), Fig. 16, 17.
- Observed differences at Huey Tak are to a large extent found between seedlots within floristic regions. This indicates a relative complex genetic pattern, Fig. 16.
- Still, a tendency to east-west (but also north-south) clinal variation is observed (Kjaer, 1999, cf. Fig. 17) which supports the observations from the international trial (cf. Fig. 15).
Figure 16. Canonical plot of the trial based on observations from Huey Tak provenance trial. A total of 30 seedlots is included from 13 floristic regions (region name shown as label in the plot). Each name thus indicates the performance of one seedlot. Large distances between observations indicate that the seedlots have grown differently. The circle indicates the size of a 95% confidence region for the seedlot average (with each observation as centre). Source: Kjaer (1999).

For detailed discussion of the technique, reference is made to Kjaer et al., 1996.

Figure 17. Average performance of the seed sources at Huey Tak plotted according to their geographic origin. Note: 95% confidence intervals are plotted for each seed lot average. Source: Kjaer, 1999.
## ANNEX 2

Budget for implementation of conservation activities (cf. Table 5)

Estimated input in manmonths (mm) and 1000 bahts (bht), 1999

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