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CONSERVATION OF GENETIC RESOURCES OF *PINUS MERKUSII* IN THAILAND

Pinus merkusii at Khong Chiam, Eastern Thailand. Photo: H. Keiding

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Forest Genetic Resources Conservation and Management Project
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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 of biological diversity has been steadily increasing over the past decades, both at the ecosystem, species and within-species levels. A number of activities have been initiated furthering conservation and sustainable use of genetic resources. Practical experiences, however, have been insufficiently documented, and 'lessons learned' from them have been little analysed and only seldom applied on a larger scale.

In 1996/97 FAO, Danida Forest Seed Centre (DFSC) and national institutions responsible for gene conservation of forest tree species in different countries, including Thailand, agreed to make a common overall evaluation of a number of *in situ* conservation areas established in the respective countries. The objective of this common programme is to provide practical advice and to assist countries in the planning and execution of conservation of forest genetic resources.

It was *i.a.* decided to develop conservation plans for four tropical tree species, focusing on *in situ* conservation. *Pinus merkusii* is one of the four 'case studies', the others are *Tectona grandis, Baikaea plurijuga* and *Acacia senegal*. The practical experience gained from the four case studies should together with practical experience otherwise available contribute to the formulation of more general guidelines for conservation of forest genetic resources of target species.

P. merkusii was chosen as a model species because of its disjunct distribution, major phenotypic variation throughout its range, and because it is one of the few species where experience with *in situ* conservation of genetic resources has been systematically gained for a relatively long period. Furthermore, the past and present distribution within Thailand is well known. *P. merkusii* is a species widely used locally and also of commercial interest. Many stands in Thailand are fragmented and declining. Today the species is threatened by extinction in parts of its distribution range despite the early *in situ* conservation efforts to safeguard the species. This makes *P. merkusii* well suited to illustrate many of the aspects which have to be taken into consideration when a national conservation plan for a particular species is to be developed.

The study has been prepared in a 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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Special acknowledgement is given to Prasit Saardavut, Winai Sirikul and Jens Granhof, who during more than 25 years with great dedication and enthusiasm have pursued and spearheaded the efforts to conserve the genetic resources of tropical pines in Thailand.

Acronyms

DANCED	Danish Cooperation for Environment and Development
Danida	Danish International Development Assistance
DFSC	Danida Forest Seed Centre, Humlebaek, Denmark
FAO	Food and Agriculture Organization of the United Nations, Rome, Italy
FORGENMAP	Forest Genetic Resources Conservation and Management Project, DANCED/RFD
PIC	Pine Improvement Centre, RFD, Thailand
RFD	Royal Forest Department, Thailand
SRC	Silvicultural Research Centre, Royal Forest Department, Thailand
SRD	Silvicultural Research Division, Royal Forest Department, Thailand
UNDP	United Nations Development Programme

Abstract

This publication documents the conservation status of *Pinus merkusii* in Thailand and proposes a conservation plan for the species based on the concept of genecological zonation. The aim is to conserve the genetic variation within the species, *i.a.* to select a number of populations from different parts of the distribution area to be protected and managed.

Genecological zonation is considered to be simple, fast and a relatively cheap tool in deciding on required conservation measures for a particular species based on already available information. This paper provides an overview of the various steps in planning and implementing conservation of the genetic resources of *P. merkusii.* A number of genecological zones are defined, and potential gene conservation stands identified in order to represent all zones in a network of conservation areas.

The value of *P. merkusii* wood is relatively low compared to many hardwoods and it is not planted on a commercial scale in Thailand at present. Nevertheless, the genetic resources found within Thailand could be valuable for future reforestation of poor and degraded soils and of importance to breeding programmes in the neighbouring countries. It is furthermore an excellent 'model' species in order to illustrate the elaboration of a conservation plan based on genecological zonation.

P. merkusii occurs naturally in Southeast Asia where it is found in Eastern Myanmar, Thailand, Lao PDR, Cambodia, Viet Nam, Indonesia and the Philippines. In Thailand it is found mainly in lower montane forest in the north at altitudes between 600-1200 m or isolated on sandstone plateaus above 1000 m alt.; smaller stands are found in the lowland (70-170 m) of southwest and eastern Thailand. Genetic variation between stands is likely to occur because of the broad range of conditions for the species in Thailand. Provenance trials support the assumptions that differences between Thai provenances exist, which may reflect adaptation to different environmental conditions, or different evolutionary histories. It is therefore recommended to conserve a network of stands rather than a few stands only.

The natural stands are widely exploited by local communities, primarily as a source of resin and for fire sticks. Furthermore, the widespread conversion of forest to farmland and frequent fires have reduced local populations of *P. merkusii* and today many stands are fragmented and declining. Especially the lowland stands, which have shown the best performance in provenance trials, are threatened with extinction within a few years.

It is recommended to focus active conservation efforts on the lowland stands in eastern Thailand in order to make it an affordable and manageable task to conserve the most valuable, genetically distinct and highly threatened Thai provenances of *P. merkusii*. Since all lowland stands from the east are found in areas under high pressure from human activities, intensive conservation actions and involvement of local people are regarded as necessary measures for conservation of these provenances.

CONTENTS

Preface i
Acknowledgements ii
Acronyms ii
Abstract iii

1. INTRODUCTION 1

2. BACKGROUND 1

3. CONSERVATION STATUS IN THAILAND 2
3.1 Distribution 2
3.2 Regeneration 3
3.3 Adaptation to fire 4
3.4 The development of land use in Thailand 5
3.5 Utilisation of natural forest 5
3.6 Plantations 6
3.7 The role of protected areas in conservation of P. merkusii in Thailand 6
3.8 Future trends 7

4. GENETIC VARIATION WITHIN P. MERKUSII 8
4.1 Field testing 8
4.2 Genetic marker studies 11
4.3 Ecogeographic variation and seed zones 11

5. GENECOLOGICAL ZONATION OF P. MERKUSII IN THAILAND 12

6. IDENTIFICATION OF POPULATIONS TO BE CONSERVED AND CONSERVATION MEASURES TO BE APPLIED 15
6.1 Genecological variation 16
6.2 Population size 17
6.3 Legal protection status of areas 17
6.4 Socio-economic aspects 18
6.5 Commercial importance 18
6.6 Management options and costs 18
6.7 Preliminary selection of conservation stands 18
6.8 Conservation measures and management options 22

7. SELECTION OF STANDS FOR ACTIVE CONSERVATION EFFORTS 25

8. IMPLEMENTATION OF CONSERVATION ACTIVITIES 26
8.1 Field surveys 26
8.2 Management and monitoring of in situ stands 26
8.3 Establishment and management of ex situ stands 28

9. CONCLUSION 28

10. REFERENCES 30

APPENDIX 1. Floristic regions and provinces in Thailand 32

APPENDIX 2. List of major P. merkusii locations in Thailand and their protection status 34

Figures

Figure 1. Natural distribution of *P. merkusii* 1
Figure 2. Natural distribution of Pinus merkusii in Thailand 3
Figure 3. Protected areas and distribution of P. merkusii 7
Figure 4. Location of Huey Bong Experimental Station and the origin of the eight Thai *P. merkusii* provenances included in the field trial. 9
Figure 5. Clusters of similar provenances of P. merkusii identified in a provenance trial at Huey Bong. 10
Figure 6. General seed zone system for Thailand 12
Figure 7. Eis' seed zones containing one or more stands of *P. merkusii*. 13
Figure 8. Genecological zonation of P. merkusii in Thailand. 13

Tables

Table 1. Thai seed sources represented in the provenance trials at Huey Bong 9
Table 2. Long term implementation schedule for conservation of the genetic resources of *P. merkusii* in Thailand 27

1. INTRODUCTION

This paper provides an overview of the various steps in planning and implementing conservation of the genetic resources of *Pinus merkusii*. The selection of stands for conservation is based on the assessment of genetic variation and use of genecological zonation as described by Graudal *et al.* (1997). Genetic variation of a species may be found among and within geographically separate populations. In order to conserve the genetic variation, a sufficient number of populations from different parts of the distribution area must be protected and managed. Genecological zonation is considered to be simple, relatively cheap and a useful tool in deciding on required conservation measures for a particular species when only limited data is available.

The aim of this study is to document the conservation status of *P. merkusii* in Thailand and to present a conservation plan, suitable conservation measures and a time schedule for implementation of the proposed conservation activities.

The note is intended for managers, administrators, planners and researchers involved in planning and implementation of the specific conservation plan, but may furthermore serve as inspiration to others engaged in conservation of forest tree species.

2. BACKGROUND

P. merkusii occurs naturally in Southeast Asia where it is found in Eastern Myanmar, Thailand, Lao PDR, Cambodia, Viet Nam, Indonesia and the Philippines (Fig. 1). The range of *P. merkusii* is between latitudes 23˚00'N and 2˚06'S and longitude 95˚30'E and 121˚30'E. It is the only pine species with a natural distribution in the southern hemisphere and its occurrence in Sumatra is the southernmost occurrence of any *Pinus*. The altitudinal range of *P. merkusii* lies between 30 and 2000 m above sea level (Cooling 1968, Santisuk 1997). The largest areas of *P. merkusii* forests are those in north-western Thailand and Eastern Myanmar and in the Aceh province in northern Sumatra. The numerous other occurrences are much smaller and widely separated (Pousujja *et al.*1986).

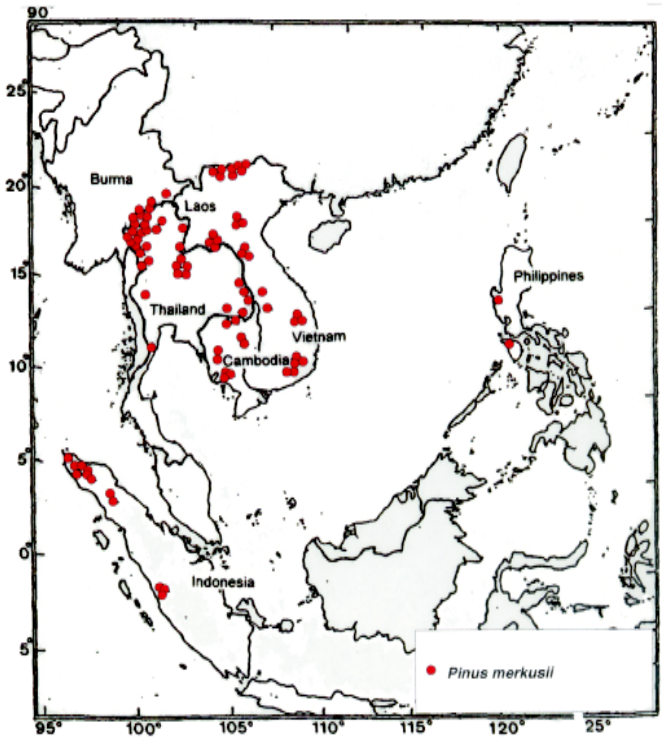


Figure 1. Natural distribution of Pinus merkusii

Although the species has not been used as a plantation species in Thailand, it was at an early stage included in provenance trials as part of the national breeding programme for pines. In Viet Nam and Indonesia the species is widely used in plantations. In Indonesia the species is mainly planted for timber and pulp and in Viet Nam the species is furthermore an important source of resin. Yielding a pulp with exceptionally long fibres, the species could be useful both for manufacture of high quality paper and possibly for enriching pulp from recycled paper. Furthermore, the species could be valuable for reforestation of poor and degraded soils.

P. merkusii is included in the world list of threatened tree species as vulnerable due to fragmentation of populations and continuing decline in area, extent and quality of habitat and continuous decline in number of mature individuals (WCMC 2000). In Thailand, the natural stands are widely exploited locally, primarily as a source of resin and for fire sticks. Extensive stands in northern Thailand were logged by the Forest Industrial Organisation (FIO) in the early 1980's without much attention to their sustainable management. Furthermore, the widespread conversion of forest to farmland destroys *P. merkusii* habitats and today many stands are fragmented and diminishing. Especially the lowland stands, which have shown the best performance in provenance trials, are threatened with extinction within a few years.

The value of *P. merkusii* wood is low compared to many hardwoods, and at present it is not planted on a commercial scale in Thailand. The justification of a specific plan for conserving the genetic resources of *P. merkusii* may thus not be obvious and the extent of recommended conservation measures must be balanced with the importance of the species. However, the genetic resources of *P. merkusii* found within Thailand have a potential for future reforestation programmes and the Thai stands may be of importance to breeding programmes in the neighbouring countries. Finally, *P. merkusii* is an excellent 'model' species for illustrating the elaboration of a conservation plan based on genecological zonation.

3. CONSERVATION STATUS IN THAILAND

Conservation status refers to the present state of the genetic resources and the risk of future genetic erosion and loss. Questions to examine are: have populations been lost? How well protected are remaining populations and are they subject to genetic erosion? What are the trends?
Assessment of the conservation status of a species is based on knowledge of: past and present geographical distribution, regeneration, present utilisation including conversion of land, exploitation of natural forest, ongoing planting and breeding programmes, and protection status of the species.

Future trends may be deducted from such information, but consideration of demographic and economic factors, development policies and legislation is also required.

3.1 Distribution

The distribution of *P. merkusii* in Thailand, as well as in its total geographical range, is scattered or disjunct consisting of isolated populations intersected by large areas where the species is absent. The distribution of *P. merkusii* in Thailand was studied in detail by Werner (1993) and is shown in figure 2.

The species occurs in three main ecological zones: mixed lowland dipterocarp forest, lower montane pine-oak forest and pine-oak savannah on sandstone plateaus above 1000 m altitude (Santisuk 1997, Cooling 1968). Its main altitude is between 700 and 1200 m. A few stands occur below 100 m altitude. Occurrence on lowland sites in the tropical regions is always linked to the occurrence of local cool winds which is important for flower induction and hence regeneration (Cooling 1968, Werner 1993). The species usually grows on acidic soils, typically red or yellow podzols and is com-

petitive on relatively poor soils as alluvial plains, sandstone ridges or granite derivatives.

The occurrence of isolated stands far away from large populations, and certainly beyond regular natural dispersal distance of seeds, may be relicts of a former more continuous population, or they may be due to rare events of long distance dispersal. Findings of fossil pollen material outside the species' present distribution *e.g.* near Kuala Lumpur and in Borneo, suggest that the species has had a wider occurrence during cooler and drier climatic periods (Werner 1993).

Pine forests in Thailand are under heavy pressure from overexploitation, conversion of forest to farmland and widely practised shifting cultivation. As a consequence *P. merkusii* stands have diminished and the species is rapidly disappearing from many parts of its range of distribution. Today, it is threatened throughout its lowland range. Extensive stands with fine conservation status are still found in northern Thailand and to a lesser extent on sandstone plateaux in north-eastern Thailand (floristic regions as referred to in this study are shown in appendix 1). Thus *P. merkusii* is not endangered at species level in Thailand. However certain populations are threatened and conservation measures are needed in order to maintain the remaining genetic variation.

3.2 Regeneration

P. merkusii is a monoecious species with male and female organs borne in male and female strobili respectively. Flowering is in February to March and the cones mature 12 months later in the north-west and after 15 months in the drier north-east of Thailand. It is wind-pollinated and has been considered principally outcrossing, though Changtragoon and Finkelday (1995) found an extraordinary high proportion of selfing. The two winged seeds are borne at the base of each well-developed cone scale favouring wind dispersal. The seeds are attached at the base of the wings and are firmly held while in a dry condition, but are quickly released when moist

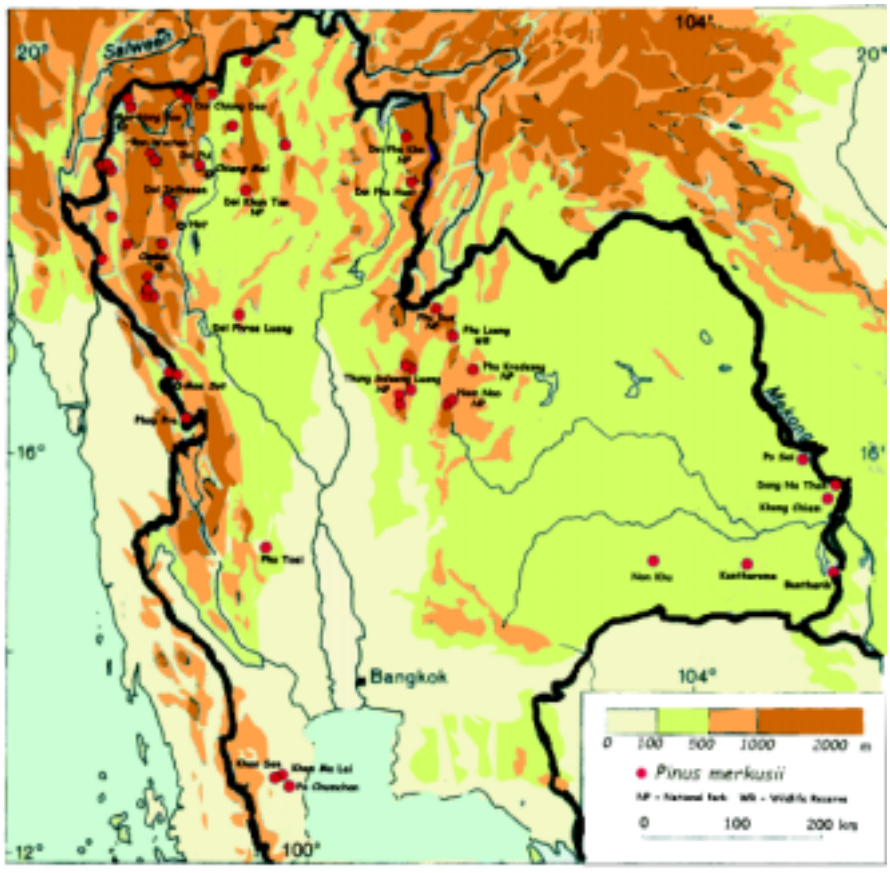


Figure 2. Natural distribution of Pinus merkusii in Thailand (modified after Werner 1993).

conditions suitable for germination are encountered. Cones are shed soon after releasing the last mature seed (Cooling 1968). Normal wind dispersal distance is probably limited to a maximum of 50 meters. Occasionally strong winds may displace seed further, but dispersal of seeds between separated stands is unlikely. However, the wide distribution of pollen by wind will counteract this effect of separation. The seeds of *P. merkusii* are short-lived and a soil seed bank is not built up. Instead, the natural regeneration strategy is based on a seedling bank (Koskela *et al.* 1995). The short lives of seeds are also compensated by the species bearing cones and seeds every year.

The species is a typical pioneer species and requires some disturbance of its growth site in order to regenerate and successfully compete with other woody species. In the natural vegetation dynamic regeneration of *P. merkusii* occurs after major disturbances like tree fall, wild fires and landslides (Koskela *et al*. 1995). Today, *P. merkusii* often gains ground after limited, reversible human disturbances such as shifting cultivation, fire, land-clearance, road building or other disturbance of climax vegetation.

P. merkusii savannah at Phu Kradeung at 1300 m. (Photo: I. Theilade)

3.3 Adaptation to fire

In the early development, *P. merkusii* seedlings follow a peculiar growth pattern called grass stage (Mirov 1967). During the grass stage, the young seedling remains suppressed for 2-4 years forming a dense cover of long needles that protect the shoot. The grass stage is considered an adaptation to seasonal drought and fire (Sirikul 1980). Later, *P. merkusii* develops a thick, fire resistant bark.

The occurrence and frequency of fires affect regeneration, and consequently species distribution. Infrequent fires at 3-5 year interval favour the regeneration of *P. merkusii* compared to most other woody species. Less frequent fires allow fire sensitive broadleaves to overgrow the pine seedlings. More frequent fires destroy the pine seedlings before they enter the grass stage.

Grass stage of P. merkusii. The needles form a dense cover that protects the shoot, which is thought to be an adaptation to seasonal fires (Photo: I. Theilade)

In the north, *P. merkusii* grows as a fire-climax tree in areas naturally exposed to fire, which plays an important role in the vegetation dynamics. However, today annual man-made fires inhibit regeneration of *P. merkusii* in many parts of its northern range.

In lowland, *P. merkusii* is a typical pioneer species invading open areas, *e.g.* after flooding or sand dune formation or abandoned farm land on sandy soil. It is normally replaced by other species in the natural vegetation succession. The southern and eastern provenances, which do not have a pronounced grass stage, are more sensitive to fires than the northern provenances. Hence, the scattered distribution of

P. merkusii reflects competition and site requirements. The occurrence of man-made fires has increased drastically over the past 100 years and has most probably influenced the distribution of *P. merkusii* profoundly initially contributing to its spread but now, as fires are almost annual, severely limiting its natural regeneration.

3.4 The development of land use in Thailand

In Thailand the total forest area declined from 28.5 mill ha equivalent to 53% of the total land area in 1961 to 14.8 mill ha or 26% of the total land area in 1995 (RFD 1996). This is in part due to an increasing population, which means that land for agriculture has become increasingly scarce. The population of Thailand increased from about 5.5 million in 1850 to 50 million in 1980, while the area under cultivation increased from about 1.5 to nearly 20 million hectares. (Meer 1981). Today the human population has passed 60 million and is expected to reach 70 million by 2020 (RFD 1996).

Conversion of forests to farmland has been most intensive in the lowland and on rich soil. The fact that *P. merkusii* grows primarily at higher altitude and on poor soil has given the species some protection throughout its natural range, since these sites are less likely to be cleared for agriculture and settlements, whereas populations in the mixed lowland dipterocarp forest have become highly threatened. Today, shifting cultivation is widely practised especially in the highlands of northern Thailand (Srisawas and Suwan 1985). As the number of people practising shifting cultivation is increasing within the same or a diminishing area the rotation period shortens, and forest is cleared before trees have reached their regenerative age. With increased pressure on land also the lower montane pine-oak forests have become subject to deforestation by farming.

Resin tapping at Si Sa Ket. A cut is made into the sapwood of mature trees and the exuded resin is collected in attached cans. Photo: H. Keiding

3.5 Utilisation of natural forest

Pinewood generally has little value as timber in Thailand as compared to hardwoods. The Forest Industry Organisation (FIO) logged natural forests of *P. merkusii* near Omkoi in the northwest in the early 1980's. The logs were intended for export to Japan, but most of the timber was rejected by the quality control due to blue stain fungi (Granhof pers. com.). Since then, commercial logging of *P. merkusii* in Thailand has ceased. The presence of mature pine stands close to otherwise heavily logged areas is due to the poor status as timber species.

More important is the extraction of resin from natural *P. merkusii* stands. Resin was earlier of commercial importance in the manufacture of turpentine and, to a lesser extent, lacquer. For extracting the resin deep cuts are made through the bark and into the sapwood of mature trees. The exuded resin is collected either from carved depressions in the tree, or collected in attached cans.

The Royal Forest Department (RFD) established one of the first resin distilleries at Si Sa Ket. The factory closed down in 1987 since most stands had disappeared by then. Today, many stands in the north are still tapped for resin, but not on a large commercial scale.

Cutting of fire sticks from the resin-rich base of the stem is still frequently encountered. The fire-sticks are sold at local markets and used in rural areas as torches. The sticks will burn with a clear flame for a long time due to the high resin content. The cutting of fire-sticks is considered destructive, as the pines become susceptible to disease or the stem breaks during strong winds.

Frequently pine forests are used for cattle grazing and hunting. To promote sprouting of fresh pasture and to drive out game or destroy their hiding places, grass is burnt every year during the dry season. Mature trees of *P. merkusii* are generally resistant to this kind of fire, but trees which have been cut for fire-sticks and resin collection have had a large portion of the protective bark removed and are prone to damage. Furthermore, fires destroy young seedlings which have not entered the grass stage.

The open pine forests, often located at high altitude with cool atmosphere and view over the lowlands, have recently become attractive recreation areas preserved for their aesthetic value.

Cutting of fire sticks from the resin rich base of the stem of P. merkusii. Khong Chiam in situ conservation area. Photo: I. Theilade.

3.6 Plantations

Plantation establishment may contribute to the conservation of genetic resources. In this regard it is important that planting is done with seed from local, natural stands. Likewise, improvement and breeding programmes based on broad genetic material may contribute significantly to the conservation of genetic resources through the retention of genetic material.

Even though *P. merkusii* is an important species in plantation forestry in the neighbouring countries only negligible areas of *P. merkusii* have been planted in Thailand so far. In 1964, 200 rai (32 ha) of Si Sa Ket provenance was planted at Baw Kaew in Chiang Mai province within the framework of a project financed by UNDP. This stand still exists and is an important gene pool as the natural stand at Si Sa Ket is rapidly declining and in danger of becoming extinct.

As *P. merkusii* is not used in plantations and reforestation in Thailand, there is consequently no active breeding programme for the species. However, the Thai provenances may represent valuable material for inclusion in breeding programmes of the neighbouring countries.

3.7 The role of protected areas in conservation of *P. merkusii* in Thailand

In Thailand, a network of protected areas contributes to the conservation of forest genetic resources. The protected areas and the estimated present distribution of *P. merkusii* are shown in figure 3.

P. merkusii is provided with legal protection at most of its remaining natural growth sites. The isolated stand at Phu Toei in Suphan Buri is found within the area of the recently established Phu Toei National Park.

In the northeast, the national parks Phu Kradeung, Tung Salaeng Luang, Nam Nao and Phu Rua include stands of *P. merkusii* as do the wildlife reserves of Phu Kieo and Phu Luang. The aesthetic and recreational value of the open pine forest in cool highland localities has undoubtedly added conservation value to these *P. merkusii* sites that have been declared protected areas.

The major part of the more extensive northern populations is found in forest reserves or protected areas. This and the logging ban in Thailand give these stands a good legislative protection.

For the eastern populations, *in situ* conservation areas were established at Khong Chiam (Ubon), and Non Khu (Surin) in 1979-83 (Sa-ardavut *et al*. 1989, Granhof 1998). A proposed conservation area at Buntharik was never established and today this lowland population is small and declining. A fourth conservation area was established at Kemarat (Ubon Ratchathani) but *P. merkusii* is no longer found in this area. This is an example that legal protection may not be sufficient to safeguard a species in a given area. Cooperation of the relevant public authorities and involvement of the local people are imperative for conservation. Nonetheless, the remaining *P. merkusii* stands within the network of protected areas and forest reserves play a crucial role in the conservation of the genetic resources of *P. merkusii*. A conservation plan will largely rely on appropriate management of the natural populations found in already established protected areas, possibly complemented with *ex situ* plantings of highly threatened populations.

A list of all major *P. merkusii* stands and their protection status is provided in appendix 2.

3.8 Future trends

The forests of Thailand are disappearing at an alarming rate and the pressure on the remaining forests is only likely to increase. As a result large areas of the remaining forests will be converted to farmland in the decades to come. Extensive tracts of pine forests have already disappeared and even stands in protected areas are still under threat. A strategy for the conservation of the genetic resources is therefore required.

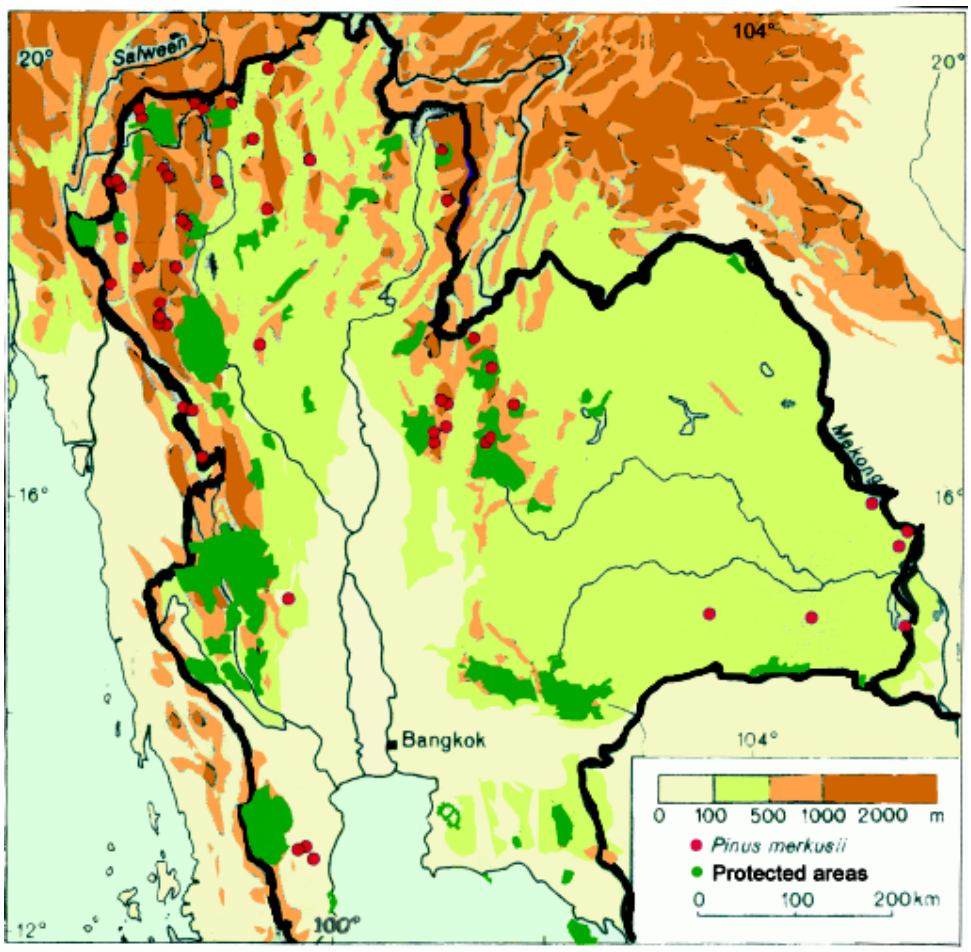


Figure 3. Protected areas are marked in green and distribution of P. merkusii marked in red (prepared after Collins et al. 1991 and Werner 1993).

4. GENETIC VARIATION WITHIN *P. MERKUSII*

Reliable information on the genetic variation, within and between geographic regions, is important in order to establish an effective network of conservation stands. The genetic variation of a species can be assessed by different techniques. It is possible to study the morphological and measurable characters in the field, in provenance trials and from herbarium material. Biochemical and molecular markers can be studied in the laboratory for gene level variation. Furthermore, it is to some extent possible to predict genetic variation patterns from ecogeographical variation. The aim is to describe the genetic variation pattern of the species in order to conserve all major gene pools.

4.1 Field testing

The study of metric characters or adaptive traits in field trials was earlier the dominating technique and is still today the most practical and valid way of assessing genetic variation. Information from such studies is essential when assessing adaptive genetic variation as a basis for conservation activities (Eriksson 1995).

P. merkusii has been subject to a number of provenance trials covering most of the species' natural distribution range. Large differences were found between provenances in height, stem form, development of the grass-tree stage, nodal habit, needle and cone dimensions, wood density and oleoresin constituents (Cooling 1968, Coppen 1998, Hansen 1999, Sirikul 1980). Mean comparison of seedling height in a provenance trial at Huey Bong and Surat, Thailand indicated a clear difference between the non-Sumatran and the Sumatran material (Chantanaparp *et al*. 1974). Differences in growth rate were also found among the Thai provenances. For example the Si Sa Ket provenance from north-eastern Thailand grew much faster than the Fang provenance from northern Thailand in both provenance trial locations (Sirikul 1980).

Based on differences in the development of seedlings Sirikul (1980) separated three groups of provenances:

- <u>High altitude provenances or ecotypes which include Fang, Khun Yuam and Mae Sanaam of Northern Thailand</u>
  Seedlings from these provenances were characterised by a pronounced grass stage and poor height growth in the first years followed by rapid increase in height growth at age 6-7.

- <u>Low altitude provenances or ecotypes which include Si Sa Ket, Ubon Ratchathani and Surin in eastern Thailand</u>
  Seedlings from low altitude provenances had an intermediate level of the grass stage and moderate height growth in the first years.

- <u>Insular provenances which include Indonesia and the Philippines</u>
  The seedlings from insular provenances do not have a grass stage. These provenances developed the best height growth at an early age. At age 10 the insular provenances were surpassed by the eastern Thai provenances both in height and diameter growth.

The provenance trial of *P. merkusii* at Huey Bong, referred to above, was initiated in 1971 at Huey Bong Experimental and Gene Conservation Station. The eight Thai provenances included in the trial are listed in Table 1.

Table 1. Thai seed sources represented in the provenance trials at Huey Bong (Hansen 1999).

Seed lot	Locality	Latitude	Longitude	Altitude (m.a.s.l.)
1005	Khao Maa Lai, Tha Yang, Petchaburi	12°45 N	99°15 E	30
1008	Phu Kradeung, Loei	16°51 N	101°47 E	1300
1012	Khun Yuam, Mae Hong Son	18°50 N	97°47 E	600
1014	Mae Tha, Lamphun	18°21 N	99°20 E	800
1015	Fang, Chiang Mai	19°52 N	99°15 E	5-600
1018	Hod, Chiang Mai	18°04 N	98°10 E	1100
1019	Non Khu, Surin	14°43 N	103°50 E	180
1020	Huey Tha (=Kantharome), Si Sa Ket	14°50 N	104°32 E	150

The Si Sa Ket provenance proved best in both height and diameter growth closely followed by the provenance from Surin. Overall, the eastern, lowland provenances showed a significantly higher wood production than the other Thai provenances (Huey Bong Experimental and Gene Conservation Station, unpublished results).

In order to support a genecological zonation of the species (cf. section 5), further analysis of the provenance trials established at Huey Bong Experimental and Gene Conservation Station was carried out in 1999. Twelve quantitative traits were analysed for the eight Thai provenances planted at Huey Bong using multivariate statistics (Hansen 1999). The location of the eight Thai provenances and Huey Bong experimental station is shown in figure 4.

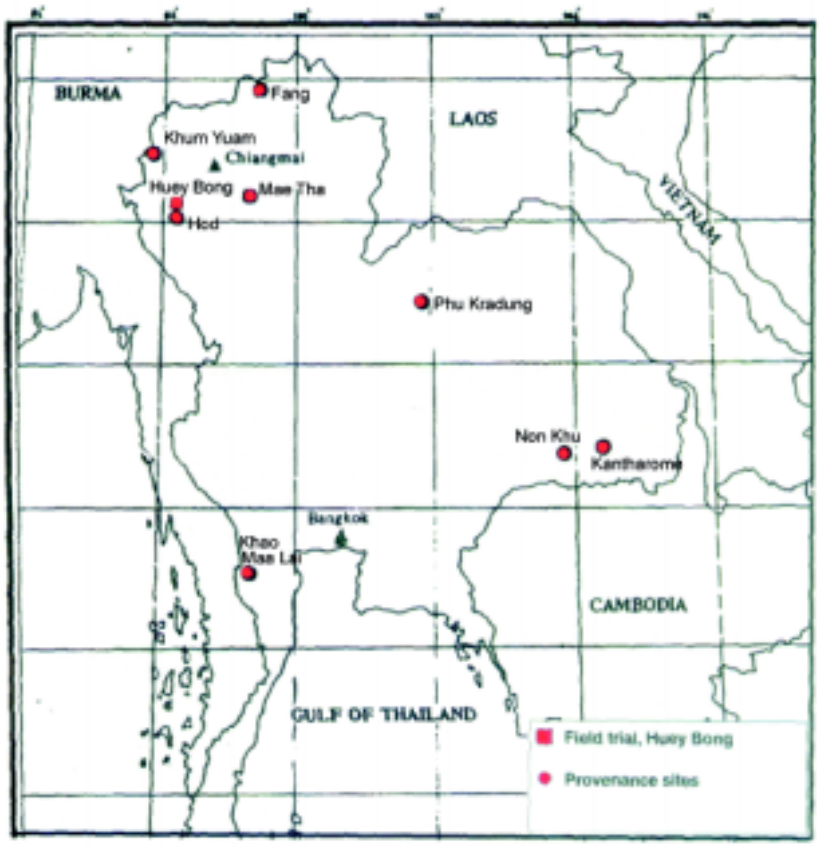


Figure 4. Location of Huey Bong Experimental Station and the origin of the eight Thai P. merkusii provenances included in the field trial.

Twelve traits (survival at the age of 1 and 5, diameter, height at the age of 5, 7, and 25, stemform, foxtailing, forking, branch coarseness, density by pilodyn, and bark thickness) were used and the differences between provenances analysed (Hansen, 1999). The applied canonical analysis combines as much information as possible from all the traits into two new, so-called canonical variables. It was found that 58% of the total variation between provenances in all analysed traits is described by the variation in the 1st canonical variable and 72% of the total variation between provenances in all traits is described jointly by the 1st and 2nd canonical variables (Fig. 5). Therefore, provenances located close to each other in figure 5 have quite similar performance, whereas provenances far from each other have grown quite differently. Please refer to Chatfield and Collins (1980) for a more detailed discussion on canonical analysis of variance.

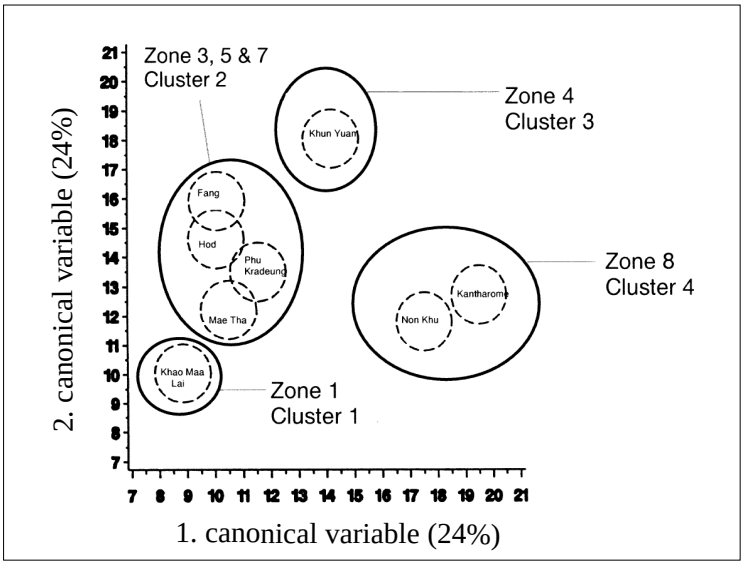


*Figure 5. Clusters of similar provenances of P. merkusii identified in a provenance trial at Huey Bong (modified after Hansen 1999). The circles around the provenance means give the size of 95% confidence regions. Provenances located close to each other (*e.g. *Non Khu and Kantharome) have quite similar performance at the test site at Huey Bong, whereas provenances far from each other (*e.g. *Khun Yuam versus Khao Maa Lai) have grown quite differently. Provenances with overlapping circles have not performed with any significant difference in the joint analysis.*

The results suggest that the eight tested Thai provenances cluster into 4 groups (cluster 1-4), where cluster 2 is somewhat heterogeneous (Fig. 5). The results reveal important genetic differentiation between provenances of *P. merkusii* within Thailand, and indicate a pattern related to geographic distance. The lowland provenances of the east differed clearly from the rest. Furthermore, the Khao Maa Lai provenance of the southwest and Khun Yuam of the northwest differed from the main cluster of provenances. The extent of the grass stage as inferred from the height at early age was found to account for the maximum variation in data. For many of the analysed traits there seems to be a northwest-southeast clinal variation. This is in accordance with studies on resin composition, which showed a northwest to southeast clinal variation in alfa-pinene and resin acid contents (Coppen 1998). It must be stressed that the above analysis is based on data from only one field trial at a single site, and that the results therefore should be interpreted with great caution. The above results will however, in combination with other available pieces of information, support the development of genecological zonation for Thailand (see chapter 5).

Only a limited number of *P. merkusii* specimens are found in Thai herbaria and so far no taxonomic studies on the morphological variation of *P. merkusii* in Thailand have been carried out.

4.2 Genetic marker studies

Molecular markers allow fast surveys of genetic variation within and between populations (Hamrick 1994). Differentiation between populations in terms of genetic markers reflects genetic drift in small populations for example in connection with founder effects or genetic bottlenecks, limited pollen flow over many generations, and/or differences between populations in their evolutionary history. Hybridisation events will also be detected by genetic markers.

Differences found using genetic markers may enable division of the populations investigated into clusters. Each cluster contains populations with a high degree of genetic similarity while the majority of genetic variation is to be found between clusters. This indicates high level of gene flow within a cluster and restricted gene flow between clusters.

DNA markers do usually not reflect effects by natural selection. The markers may therefore not detect important genetic differentiation following divergent natural selection in a few generations. Recent studies have shown that high differentiation of adaptive traits can be present with only slight allelic differentiation, thus limiting the use of molecular markers for population diversity studies (Muona 1990). This is supported by the fact that several studies of forest trees have shown larger differentiation between adaptive traits than between biochemical markers (Karku *et al.* 1996). Therefore, genetic marker studies cannot on their own be used as the basis for elaboration of conservation strategies but should rather be used as a supplement to elaborate the genecological zonation.

Changtragoon and Finkeldey (1995) carried out a genetic inventory of 11 natural populations of *P. merkusii* in Thailand. Allelic differentiation between populations was relatively high (F_{ST} = 0.104) compared to other studies on *Pinus* (Savolainen 1994). The study by Changtragoon and Finkeldey (1995) also revealed that outcrossing rates varied, to a surprisingly high degree, between the populations investigated. Ecological factors such as scarcity of pollen due to low population density, poor synchronisation of flowering, and over-maturity of most stands resulting in limited flower production are mentioned as possible reasons for the high selfing rates in some stands. However, there can also be genetic explanations (Willams and Savolainen, 1996), in which case the observed differences between populations in selfing rates can indicate genetic differentiation between populations. To conclude: the marker studies suggest that the different Thai populations of *P. merkusii* may have been fairly isolated over an evolutionary time span, and the resulting genetic differences between populations would justify conservation of more populations.

4.3 Ecogeographic variation and seed zones

A comparison of a species' distribution with well-defined ecological zones provides guidance to the likely ecogeographic variation of the species. It is generally assumed that similarity of ecological conditions implies similarity of genetic constitution and an ecogeographic survey will therefore provide a first indication of possible genetic variation. Ecogeographic surveys can be used for several purposes. In forestry they have primarily been used to define tree seed zones with specific recommendations for seed collections and utilisation of seed sources.

There are different perceptions of the seed zone concept (Barner and Willan, 1983), and often the applied definition it is not clearly stated in available seed zone systems. Sometimes seed zones are constructed in order to identify regions where all seed sources are expected to perform more or less the same. OECD (1974) defines a seed zone as an area, or group of areas, subject to sufficiently uniform ecological conditions to assume similar phenotypic or genetic characters within species (here after Barner and Willan 1983). Seed zones thus defined can be seen as seed collection units, and will therefore normally be geographically continuous regions. Seed zones in this perception will form an important tool for estimating expected genetic variation between populations within a country.

However, in other cases seed zones have been constructed in order to identify areas, where given seed sources are expected to grow well, or even expected to perform better than other seed sources, based on field trials. Seed zones defined in this way can be the basis for matching seed sources to planting sites, and for development of guidelines for safe seed transfer.

The majority of available seed zone systems are based on ecological surveys. Exceptions exist where seed zones are based mainly on results from intensive field testing (Wellendorf *et al.* in press) or combinations of field test and ecological surveys. Such seed zones will often be species specific.

For Thailand, Eis (1986) prepared a general seed zone system based on topography, soil, climate, and natural vegetation. The seed zone system is shown in fig. 6.

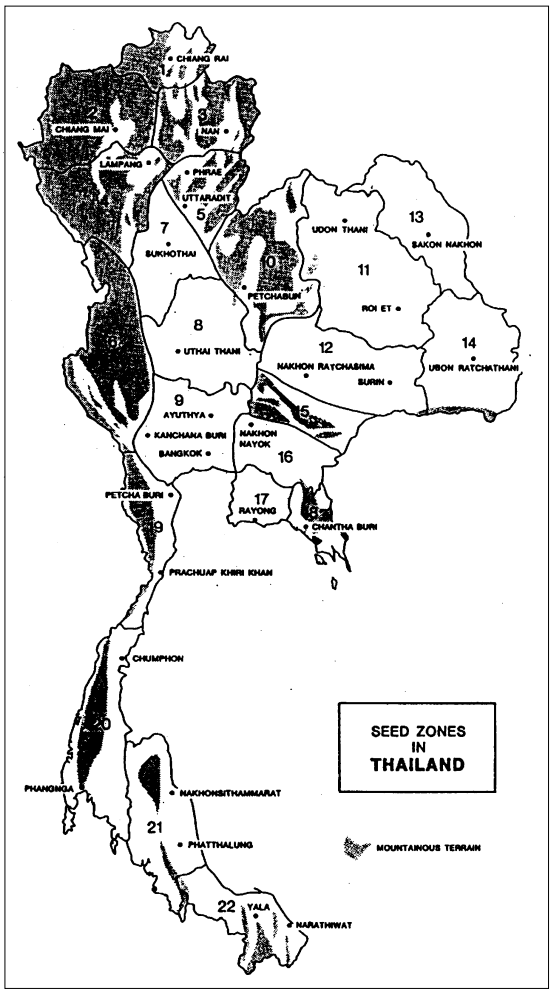


Figure 6. General seed zone system for Thailand (Eis 1986).

5. GENECOLOGICAL ZONATION OF *P. MERKUSII* IN THAILAND

Genecological zonation is a practical tool in the selection of populations to be conserved. It implies identification of areas with uniform ecological conditions and subject to none or limited gene flow from surrounding areas. A genecological zonation is drawn up based on available information on distribution of genetic variation within a species as referred from field testing, genetic marker studies and ecogeographic variation (cf. section 4.1-4.3). In reality, genecological zonation is often primarily based on ecogeographic variation due to a lack of field trials and genetic marker studies. Results of the latter should be incorporated in a genecological zonation whenever possible.

Genecological zonation may be prepared as one common system for several species or as a specific system for one species. It is usually based on existing data on natural vegetation, topography, climate and soil. Information from provenance trials and genetic marker studies may, if available, be used to test the validity and adjust the zonation. The construction of genecological zones is described in more detail by Graudal *et al*. (1997).

Compared to seed zones, genecological zones differ in at least one aspect. A seed zone may be composed of a group of ecologically similar but geographically separate areas. If the geographic separation constitutes barriers to gene flow, such areas should at least initially be regarded as different genecological zones. The close relationship between the concepts of seed zones and genecological zones implies that the seed zones for Thailand can be used as a basis for developing genecological zones for *P. merkusii* in Thailand. However, geographically separate areas included in the same seed zone have to be considered different genecological zones.

Figure 7. Eis' seed zones containing one or more stands of P. merkusii. Drawn on map from Werner (1993).

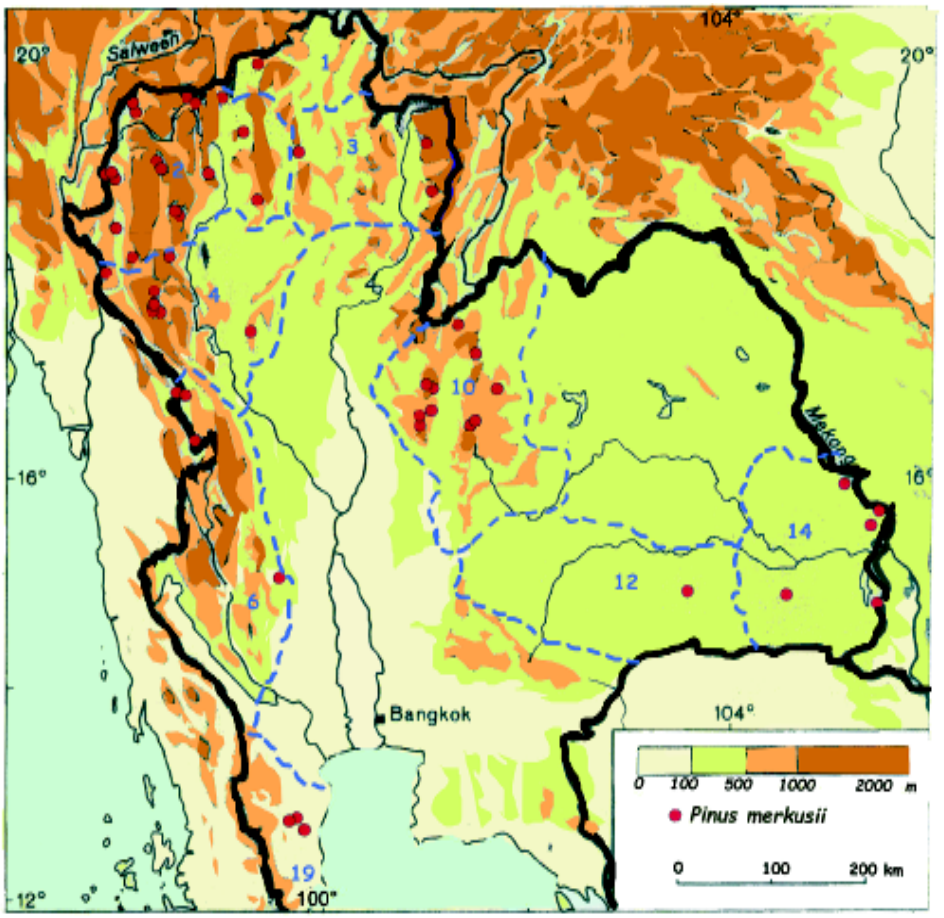
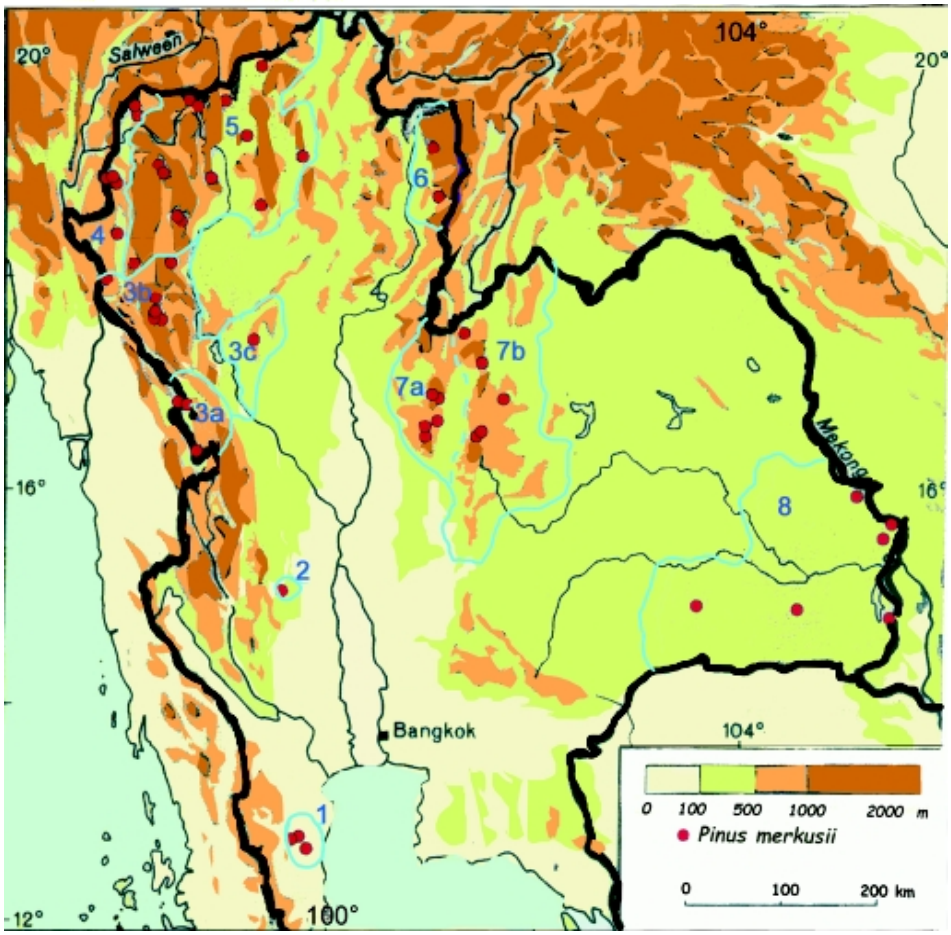


Figure 8. Genecological zonation of P. merkusii in Thailand. Drawn on map from Werner 1993.



Genecological zonation should ideally be specific for individual species, or at least for major groups of species. Different species included in a given gene resource conservation programme may be different in several ways. They may vary in reproductive biology, they may react differently to environmental clines or heterogeneity, and they may reflect entirely different life histories in terms of evolution, migration, hybridisation events, or human utilisation. Thus species with the same distribution may show entirely different pattern of genetic variation within that area. Species-specific zonation will require the same basic data as common zonation. For economic reasons - and due to lack of species-specific data - such specific systems will generally be limited to species of major economic importance.

It should be noted that genecological zonation is not something fixed, but should be subject to continuous revision as more information becomes available. Additional information from morphological studies, provenance trials and genetic marker studies may be of particular value for such revisions.

A genecological zonation for *P. merkusii* is suggested based on Eis' seed zones of Thailand but modified according to the species distribution and likely gene flow between individual populations. The delineation of the different genecological zones is supported by the results from provenance trials (see section 4.1).

Figure 7 shows Eis' seed zones encompassing *P. merkusii*. Based on these zones a genecological zonation for *P. merkusii* has been suggested. The genecological zonation is somewhat different from the seed zones reflecting the geographical isolation of some stands and expected gene flow between others. Boundaries were drawn so that separation of continuous forest areas was avoided. The genecological zonation distinguishes eight zones.

Genecological zone 3 has been divided into 3 sub-zones because groups of stands are geographically separated and grow at different altitudes, which is likely to restrict gene exchange between stands though they occur in the same ecological zone. It can be discussed whether zone 3 is too heterogeneous and should be divided into more zones instead of subzones. This illustrates that the number and size of genecological zones are to a certain degree relative. Sub-zone 3a is equivalent to the northernmost part of Eis' seed zone 6. The stands in sub-zone 3a are found at 430-450 m altitude and might thus be more similar to the stand at Phu Toei in the genecological zone 2, which is found at the same altitude. Due to their proximity to the stands at Omkoi and Doi Phra Luang in zone 3 they have been included in this zone. Sub-zone 3b and 3c are part of Eis' seed zone 4. Sub-zone 3b encompasses the extensive stands on the Omkoi plateau at 850-1080 m altitude. Sub-zone 3c includes the isolated stand at Doi Phra Luang plateau at 700 m altitude. This stand is separated from the other stands in zone 3 by a wide stretch of lowland.

Genecological zones 4 and 5 are more or less equivalent to Eis' seed zone 2 and the western part of Eis' seed zone 1. Rather than an east-west boundary based on a north-south climatic gradient, a north-south heading boundary has been chosen to divide this area. This division follows possible barriers to gene flow caused by mountain ridges or valley bottoms. Although the altitudinal range of *P. merkusii* considered rangewide is 30-2000 m a.s.l., the range in northern Thailand is 400-1300 m and mountain ridges and valley bottoms may thus theoretically constitute physical barriers to gene flow in this area. This assumption is supported by the multivariate analysis of quantitative traits in *P. merkusii* carried out by Hansen (1999), who found that stands at Khun Yuam and Mae Tha in the northwest differed significantly, cf. section 4.1 and fig. 5.

Due to the extensive and more or less continuous stands in the north it is expected that gene exchange is more prevalent between genecological zones 3, 4 and 5 than between other zones. Thus populations of the north are probably closer related to each other than to more isolated stands.

Genecological zone 6 encompasses two stands in the province of Nan near the border to Lao PDR.

These stands might be closer related to stands in Lao PDR than to the stands in the Northwest.

Genecological zone 7 is almost equivalent to Eis' seed zone 10 but has been divided into 2 subzones as lowland separates the stands in Phitsanulok (zone 7a) from those in Loei and Phetchabun (zone 7b).

Genecological zone 8 encompasses the easternmost lowland stands near the border to Lao PDR and Cambodia. It is equivalent to Eis' seed zone 14 and the easternmost part of seed zone 12. The stands in genecological zone 8 are probably remnants of a former more continuous distribution of lowland *P.merkusii*.

The multivariate analysis of quantitative traits in *P. merkusii* (Hansen 1999) in general supports the proposed genecological zonation. The study revealed that the southwestern and eastern lowland provenances differ significantly from the rest. In addition, the stand at Khun Yuam in the northwest was found to differ significantly from the rest. Moreover it revealed differences, though for the most part not significant, among populations in the north and northeast (zones 3, 5, and 7). Thus the multivariate analysis indicates an east-west rather than north-south division of the northern stands. An east-west division has been followed in the present genecological zonation.

The exact delineation of genecological zones is often difficult where a species has a more or less continuous distribution over a large geographical area, as is the case with *P. merkusii* in northern Thailand. A clinal variation is to be expected from north to south and east to west. Geographical features like mountain ranges and valleys are useful in the overall establishment of boundaries but uncertainty as to whether stands near the borders belong to one zone or the other are inevitable. If the variation within a species is indeed gradual, it does not matter to which zone the border stands are assigned. In any case the final distribution of stands to zones will have to be based on available information and the genecological considerations mentioned above. Minor uncertainties should not discourage the practical use of genecological zonation.

6. IDENTIFICATION OF POPULATIONS TO BE CONSERVED AND CONSERVATION MEASURES TO BE APPLIED

In the selection of populations to be conserved the aim is to secure the genetic variation, that is to conserve both stands which have proved promising for desired traits in provenance trials, and stands of less obvious value. The latter should also be included since these populations may contain genetic material of unknown importance for future adaptation and breeding.

The specific criteria for the identification of conservation stands of *P. merkusii* in Thailand are:

- Genecological variation: secure representation in all genecological zones. Actual selection may furthermore be supported by knowledge on genetically controlled morphological variation in specific characters among stands. Genetic diversity assessed by genetic markers should be included as such knowledge becomes available.
- Population size: large enough to conserve the genetic variation and provide conditions for adequate regeneration.
- Legal conservation status: legally protected stands preferred.
- The socio-economic context: areas without serious human pressure preferred; alternatively areas with good prospects for involving the local people in appropriate management.
- Commercial importance.
- Management options and costs of protection and management: interventions to ensure adequate regeneration should be possible considering the environmental as well as the socio-economic context. If interventions are very costly, conservation may be unrealistic.

Choice of conservation measures for a given population depends on the conservation status and the nature of the biological material to be conserved. Where all criteria are positively fulfilled, *in situ* conservation will be possible. Where difficulties exist, *e.g.* with conservation status or population size, one may have to identify another population or resort to *ex situ* conservation. *Ex situ* conservation is here referred to as *ex situ* plantations, because the long period of time and the large areas required for periodic regeneration of stored seed, generally make *ex situ* storage of seeds unsuitable for evolutionary conservation of woody perennials (Graudal *et al*. 1997). This principle is valid also for *P. merkusii* (cf. section 3.2). Seed storage may constitute an important interim measure for some species. *P. merkusii* seeds can be kept in storage after careful handling and drying. If kept under optimal condition they may maintain germination capacity for 15-20 years (DFSC 2000). However, the eastern lowland provenances, of which the seed matures in the rainy season, are difficult to dry sufficiently (Granhof 1981). It is therefore recommended that seed be sown as quickly as possible after harvest.

Based on an overall evaluation of all criteria listed, a representative set of stands can be identified for conservation and the most appropriate conservation measures chosen. The implications of each criterion for conservation of the genetic resources of *P. merkusii* in Thailand are briefly assessed below.

6.1 Genecological variation

A comparison of the geographical distribution of *P. merkusii* with the genecological zones provides the overall framework for sampling of conservation populations. To cover the expected genetic variation, at least one population per zone should be conserved.

P. merkusii in mixed forest, northern Thailand.
Photo: H. Keiding.

Whenever possible, more than one population per zone should be identified to minimise the risk of loss due to external events (Graudal *et al.* 1997). For a wind pollinated species like *P. merkusii*, two stands are believed to be appropriate, whereas insect and animal pollinated tree species may need more stands per zone. However, the number of stands per zone is also dependent on the size and homogeneity of each zone (cf. Chapter 5). Major *P. merkusii* stands in each genecological zone are listed in appendix 2. A map of Thailand with names of locations with *P. merkusii* is shown in Figure 2.

Where a genecological zone contains only one stand, there is no choice of selection; conservation must necessarily encompass the only stand available. This is the case in Phu Toei (zone 2).

Where *in situ* conservation measures are not applicable, *i.e.* if stands are too small, isolated and threatened by encroachment, *ex situ* conservation may be the only option. The stands in zone 1 and 8 are all small and threatened by extinction. For zone 1 it is probably realistic to conserve *in situ* only the stand of Pa Chumchon Khao Son while the other stands are very small and in the process of disappearing. In zone 8 probably only the stand at Khong Chiam can be protected *in situ*. Thus *ex situ* conservation should be considered as an option to conserve the genetic material from the other stands that cannot be conserved *in situ*.

6.2 Population size

The size of a conservation stand depends on species and site-specific aspects. Where a target species grows in mixed stands, the conservation area has to be larger than where the species occurs in pure stands. As a rule of thumb, an *in situ* stand of a wind-pollinated species should initially consist of at least 150 and preferably more than 500 interbreeding individuals. The final stand size should be 500-1500 individuals or more per species (Graudal *et al.* 1997).

For the establishment of *ex situ* conservation stands seed should be collected from minimum 50 trees at a distance of 100 m from each other. If the mother stand is large and the mother trees are supposedly unrelated, seed collection from 25 trees should be sufficient (Guldager in FAO 1975). This is the internationally recommended practice in forestry. Mother stands with less than 150 trees should be avoided, because the relationship between trees is rarely known and individuals are likely to be related. *Ex-situ* conservation from such stands may on the other hand be necessary in situations where these contain the last remaining trees in an area. If only small isolated stands are present within a given genecological zone, collection from several stands and subsequent mixing of seed is an important option in order to capture most possible genetic variation for the founding of *ex situ* stands. When establishing *ex-situ* conservation stands, the aim should be a final stand size of not less than 500-1500 individuals. The recommended numbers are based on population genetic considerations (Graudal *et al*. 1997).

6.3 Legal protection status of areas

The practical possibilities for protection should be taken into consideration when selecting stands to be conserved. Hence stands occurring in protected areas are usually preferred to those which are not, because they have already been given legal protection.

Many of the *P. merkusii* stands are found within national parks or wildlife reserves. For example, Phu Toei in zone 2 is within the newly established Phu Toei National Park. Many of the northern stands in zone 3-6 and all stands in zone 7 occur in national parks or wildlife reserves.

Furthermore, *P. merkusii* has been a priority species for conservation in Thailand since 1973 (Sa-ardavut *et al.* 1989, Granhof 1998), when *ex situ* conservation of pines including *P. merkusii* was started at Huey Bong, Nong Krating, and Mae Sanaam in Chiang Mai. *In situ* conservation

was initiated in 1979 in east Thailand to conserve lowland stands of *P. merkusii* for seed production, selection and possible further breeding (Saardavut and Chairuangsirikul 1988). The activities in eastern Thailand started at Non Khu (Surin) and were later expanded to include stands at Khong Chiam (Ubon Ratchathani) and Kemarat (Ubon Ratchathani). These conservation stations are good starting points for further activities.

6.4 Socio-economic aspects

Regardless of the early conservation efforts several populations of *P. merkusii* are decreasing and approaching critical population sizes. The south-western and eastern lowland provenances are more threatened than the northern highland ones despite the early initiatives aimed at protecting the lowland ecotypes. This is mainly due to encroachment and failure to involve the local people in the conservation of the species (Granhof 1998). In areas with high pressure on the remaining forests it is imperative to increasingly take socio-economic aspects into consideration and to engage the local communities in conservation efforts. In some cases it might be necessary to revert to *ex situ* measures.

6.5 Commercial importance

The lowland ecotypes of *P. merkusii* from the east have proved the most promising in provenance trials in regard to height, diameter and volume production. Due to the lack of pronounced grass stage the lowland provenances can be propagated in nurseries and used for plantations and reforestation schemes. Hence they are regarded as the most valuable from an economic point of view.

In addition to probable lack of overall adaptation, and in consideration of genetic pollution, the lack of pronounced grass stage, and frequent occurrence of fires it might not be appropriate to use lowland provenances for reforestation schemes in northern Thailand. Highland provenances, which show an impressive growth in natural stands, are those of Doi Phra Luang in Tak, Thung Salaeng National Park, and Doi Mae Tai in Chiang Mai. These stands harbour trees up to 60 m in height and 120 cm in diameter which are the largest in Thailand (Werner 1993). Therefore, natural stands in the highland may also be of potential economic interest for future breeding programmes and planting schemes.

6.6 Management options and costs

The management measures necessary for a given population targeted for conservation depend on the protection status of the area, the size and status of the stand, plus the actual or potential threats (FAO 1989). In general, areas that require less costly management should be chosen. Thus, stands found in national parks, wildlife reserves or at gene conservation stations can often be included in a conservation plan without additional costs.

Areas where natural regeneration seems to be good should be chosen rather than those where intensive management is required. Likewise, areas under little pressure should be chosen to those under heavy pressure in order to increase the probability of success.

6.7 Preliminary selection of conservation stands

In order to select stands for conservation, the status of *P. merkusii* populations in all zones are reviewed below, zone by zone. Based on the available information on population size, legal protection, social aspects, commercial interest, management options and costs, stands in each genecological zone are proposed for conservation. Ideally at least two stands per zone should be selected to minimise the risk of loss due to external factors. In the current plan, one stand has been selected for many of the zones. This is because the conservation status in most zones is gen-

erally good and in order to keep the conservation plan at a manageable level. More stands have been appointed only in zones where there is an immediate risk of loss (zone 1 and 8).

For some of the genecological zones, more information is wanting and further surveys and inventories should be carried out in order to confirm the presence, size and status of stands before the final selection for conservation is made.

The final number of stands for which active conservation efforts are to be implemented will depend on an overall prioritisation of *P. merkusii* compared to other forest tree species in Thailand.

Please refer to the genecological zonation shown in figure 8.

Genecological zone 1:

The stands in zone 1 are all small and declining. Two stands are found at dry sites on the slopes and ridges of Khao Son and Khao Maa Lai at around 400 m altitude around the Kaeng Krachan Dam. The southernmost limit of *P. merkusii* in Thailand is found at Paa Chum Chon at elevations of about 70 m altitude, near the eastern coast of Cha-am District in Phetchaburi. This is also the

Trees scarred by resin tapping, Khong Chiam. Photo: Allan Breum Larsen

lowest elevation of *P. merkusii* in Thailand (Santisuk 1997). Due to the isolated occurrence at the extreme of the range this source may harbour special characteristics developed through intense selection.

In situ conservation is only realistic for the largest stand at Paa Chum Chon, which encompasses less than 300 trees (Santisuk 1997). The two other stands are reportedly too small and in the process of disappearing. Thus the stand at Khao Maa Lai is reduced to about 10 trees. Seed collection and *ex situ* conservation should be considered as a complementary option to conserve the genetic material from all three stands.

Stand proposed for *in situ* conservation: Pa Chumchon Khao Son. As a complementary measure, *ex situ* conservation of material, preferably from all three stands, should be considered.

Genecological zone 2:

The only stand in zone 2 is at Phu Toei within the newly established Phu Toei National Park. The stand consists of more than 3000 trees and is not critically endangered. However, annual fires prevent regeneration and today the stand consists of even-aged mature trees.

Stand proposed for *in situ* conservation: Phu Toei.

Genecological zone 3, 4, 5 and 7:

Zone 3, 4, and 5 and to a lesser extent 7 of the northwest encompass many extensive populations of *P. merkusii*. In these zones the species grows as a kind of climax tree at mid-altitudes on poor soil, albeit probably still dependent on some disturbance in order to regenerate and compete efficiently. *P. merkusii* is not in danger of extinction in any of these zones, but local stands may disappear due to conversion of land and shifting cultivation. If the full range of genetic variation is to be protected, selected stands within each zone should be nominated and monitored as gene conservation stands. It is not critical which particular stands are chosen as long as their population size is sufficient for conservation.

Genecological zone 3:

The stand at Omkoi plateau is the largest, continuous *P. merkusii* stand in Thailand. There is a good regeneration with many young trees and no particular management intervention is required.

The stands found at the Huey Bong Experimental and Gene Conservation Station are protected as long as the Station is in operation. Thus these stands can easily be included in a conservation plan without additional resources.

Stands that could be considered for in situ conservation in zone 3:

3a: Mae Sod
3b: Omkoi, Huey Bong
3c: Doi Phra Luang

Genecological zone 4:

P. merkusii is not in danger of extinction in this zone, but local populations may disappear due to conversion of land and shifting cultivation. Khun Yuam is one of the largest stands of *P. merkusii* found within reserved forest. Parts of the stand may be located inside Mae Surin National Park

but renewed field work is needed to confirm this. The stand at Khun Yuam grows at 600 m altitude, which is the lowest elevation in zone 4 and 5 (the stand reported at Doi Saket at 400 m altitude has probably disappeared). Furthermore, Khun Yuam proved significantly different from other northern provenances in a multivariate analyses (Hansen 1999). The three stands along road from Mae Hon Son to Pai are exploited intensively for resin and will be difficult to protect. Monitoring and potential conservation efforts are suggested for Khun Yuam.

Stand to be considered for in situ conservation in zone 4: Khun Yuam.

Genecological zone 5:

Several stands of *P. merkusii* are found in zone 5 but little is known of the extent and conservation status of the stands. It seems that many of the stands in zone 5 are subject to intensive resin tapping. Surveys are needed in order to verify if conservation measures are required and if so, identify stands for conservation.

The stand at Ban Wat Chan in zone 5, is the third largest in Thailand. In 1986 the Forest Industry Organisation started logging the *P. merkusii* forest around Ban Wat Chan. The project was stopped after severe protests by villagers, who later declared a community forest in the area. Today Thai and Karen villagers are involved in a royal project aiming at conserving the forest through sustainable use. Resin tapping of pines still takes place and a management plan for *P. merkusii* might be needed to ensure its survival and regeneration in the area. Valuable experience on villagers' involvement in the conservation of pines might be gained from Ban Wat Chan, which is therefore included as an example.

Stand proposed for in situ conservation in zone 5: Ban Wat Chan

One more stand could be chosen depending on further surveys.

Genecological zone 6:

Two populations are found in zone 6: Doi Phu Kha and Doi Phu Huat of which the first is within Doi Phu Kha National Park. The size and status of the populations are not known and surveys are needed in order to elaborate whether active conservation measures are needed.

Stand proposed for conservation in zone 6: Doi Phu Kha.

Genecological zone 7:

Two stands are found within zone 7a: Thung Salaeng Luang and Thung Nang of which the first is within Thung Salaeng National Park. The stands at Thung Salaeng Luang include 60 m tall trees, which are the tallest pines in Thailand. The park is subject to annual fires and the regeneration of the stand should be monitored.

Stand proposed for conservation in zone 7a: Thung Salaeng Luang National Park.

All stands in zone 7b are found within national parks or wildlife reserves. The stand at Phu Kradeung is in good condition though annual fires impede the regeneration. The conservation status of the stands at Phu Rua National Park and Phu Kieo and Phu Luang Wildlife Reserves is unknown. It is recommended to survey these stands and monitor the regeneration.

Stand proposed nominated as conservation stand in zone 7b: Phu Kradeung.

Genecological zone 8:

All stands in zone 8 are severely threatened. Most of the stands approach critical population sizes and are rapidly declining. Less than 1000 individuals are left in the gene conservation stands of Non Khu, Khong Chiam and Kantharome (Si Sa Ket). The seed setting of the remaining trees is poor possibly due to damage by fire-stick cutting, resin tapping and fires. Only around 100 trees are left in the two small stands of Po Sai and Dong Na Than. The stand at Buntharik was until recently presumed extinct when a farmer directed the attention of Forest Department to a stand in this area. The rediscovered population is estimated at around 1000 trees but a survey is underway. Thus it may turn out that a previously unknown stand is in fact the largest remaining in the lowland. The stand at Kemarat has most probably disappeared within the last 10 years.

Due to their distinctness from the other provenances, promising performance in provenance trials, and their status as critically endangered, **the lowland populations of zone 8 should be given the highest priority for conservation.**

The stands at Non Khu and Kong Chiam are found within the existing *in situ* conservation areas established in 1979 and 1981. The gene conservation stations at Non Khu and Khong Chiam are believed to be good starting points for intensified conservation efforts of the lowland *P. merkusii*.

Stand proposed for *in situ* conservation in zone 8: Khong Chiam. The stands at Po Sai and Dong Na Than should be properly surveyed and monitored. It is recommended to collect seed from the small and declining stands at Non Khu and Kantharome (Si Sa Ket) for the establishment of *ex situ* conservation stands. If enough seed cannot be collected from the Si Sa Ket provenance, it may be complemented by seed from the plantation of Si Sa Ket provenance in Baw Kaew, Chiang Mai (see section 3.6). The stand at Buntharik should be surveyed and threats to the stand evaluated to assess whether it should be included in the conservation plan.

6.8 Conservation measures and management options

At present, conversion of forest land and frequent fires are the most serious threats to *P. merkusii* in Thailand. Especially the eastern lowland stands (zone 8), which lack pronounced grass-stage and grow in heavily populated areas are susceptible to both. Unsustainable cutting of fire-sticks and resin tapping of remaining stands also pose a threat. Thus measures to avoid conversion of land, and to control or counteract annual fires are important for many of the stands. In some areas management plans to control resin tapping and fire-stick cutting have to be elaborated. Resin tapping as a source of income for rural communities should be recognised. The question should however be addressed through establishment of community plantations as is the case in Viet Nam where the species is popular for this use. The lowland populations in the east have a special potential for this due to the absence of grass stage. In the following, possible realistic conservation measures for the selected stands in the eight genecological zones are outlined.

All stands in zone 1 are under heavy pressure from encroachment and threatened by extinction. Local exploitation such as clearing of land, resin tapping and fire-stick cutting accelerates deterioration of the stands. Involvement of the local people and ensuring local benefits are necessary in order to conserve this provenance of *P. merkusii in situ*. Cutting of trees, resin tapping and fire-stick cutting will have to be controlled.

Paa Chum Chon at 70 m altitude consists of a few hundred trees. For the two stands at Khao Son and Khao Maa Lai at 400 m altitude population size is reportedly critically low and intensive conservation measures are necessary in order to save the genetic material. Seed collection and perhaps grafting should be carried out in order to multiply the populations. Subsequently, the planting material may be raised *ex situ*. The isolated occurrences of *P. merkusii* in Phetch-

aburi are seen as either a rare event of long distance dispersal at the extreme of the species range or as a relict of a former more widespread distribution. It can be argued that these southern stands are disappearing as a consequence of natural succession with broadleaf species (Santisuk 1997).

As a first measure, it is recommended that the Forest Department undertakes inventories of the stands in zone 1. The options for conserving the lowland provenance *in situ* should be evaluated and possibilities of involving local villagers should be investigated. Establishment of a managed nature reserve could be considered. Collection of seeds from the three remaining stands and establishment of *ex situ* stands is a complementary option to conserve the genetic material of zone 1.

Phu Toei in zone 2 is an example of a site where the lack of regeneration has created stands of mature even-aged trees, which will soon have reduced seed production capacity because of high age. Apparently annual fires destroy regeneration of these south-western provenances that do not have a pronounced grass stage. Some years of intensive fire management are necessary to secure a new generation. It is suggested that fire-protection be carried out for a manageable sized area at a time in order to enhance regeneration in that particular area. When successful regeneration is ensured in one area, the intensive fire management is shifted to another area. In this way a rejuvenation of the stand at Phu Toei would be assured.

If fire protection is insufficient to secure regeneration of the species in Phu Toei National Park, a more intensive management including raising of seedlings in nurseries and subsequent enrichment planting may be considered. This kind of management would have to be included in the management plan for Phu Toie National Park and undertaken in collaboration with staff from the park.

Presentations and discussions among staff from the Regional Forest Office, the local NGO Naturecare and community leaders of the three neighbouring communities of Khong Chiam in situ conservation area. (Photo: I. Theilade).

The network of national parks, wildlife reserves and other protected areas in Thailand renders the species good protection throughout most of its range. Thus, the species is not regarded as threatened in the north and northeast (zone 3-7). Proper management of the existing national parks and protected areas would be sufficient to conserve most stands. For some of the areas improved fire management is needed in order to ensure proper regeneration. It is suggested that selected stands in zone 3-7 are monitored and active conservation efforts are applied only if necessary in order to safeguard particular stands. Cutting of fire-sticks and resin tapping have to be controlled, substituted with other income sources, or planned in a sustainable way for some areas. The block plantings at Huey Bong Experimental Station should be considered for establishment of resin production trials on a sustainable base.

It should be noted that a forest area at Mae Sanaam (zone 4) has been identified and proposed developed as a pilot area with a status of Managed Nature Reserve (IUCN category 4). This would allow for limited management for conservation as well as sustainable local use of the forest. It is envisaged that Royal Forest Department/Silvicultural Resource Division establishes links to a local NGO and the local hill tribes, Lawa, Karen and Thai Khun Muang in order to establish a sustainable management system of the forest including *P. merkusii* (Sumantakul and Granhof, 2000).

The lowland stands in zone 8, the eastern region, are critically endangered and in the process of disappearing. Active conservation efforts are needed in order to ensure the survival of the eastern provenances in Thailand. The involvement of local people is found to be crucial for the future conservation and management of the lowland ecotype of *P. merkusii*.

At the moment Khong Chiam *in situ* conservation area has been identified for the FORGENMAP pilot project for ecosystem conservation outside protected areas. The over-all objective is to develop a model for community based conservation of forest genetic resources through co-existence of humans and forest with focus on ecosystem rehabilitation and maintenance (Granhof 1998; Sumantakul and Granhof 2000).

In line herewith rapid rural appraisal (semi-structured interviews) was carried out in three neighbouring communities of the Khong Chiam *in situ* conservation area as part of a FORGENMAP training course August 1999. Presentation and discussion of the findings with community leaders took place at the village Na Plo Nua. The Ubon Regional Forest Office facilitated the Rapid Rural Appraisal work together with the local NGO, Naturecare, which has a well-developed community forestry programme in nearby Pa Taem National Park buffer zone. The initial contact between the Regional Forest Office, Naturecare and local communities could serve as a foundation for future conservation initiatives for Khong Chiam *in situ* conservation area.

Management and protection of the area will have to include more effective fire protection in order to ensure regeneration of *P. merkusii* as well as other tree species. This could be done in combination with controlled burnings in the beginning of the dry season. It should be kept in mind that pine seedlings are sensitive to fire for several years during their establishment. Exclusion of fire for one or two years only, may cause accumulation of dry plant material that may cause more severe and fatal fires later on. Removal of inflammable material such as pine straws and grass in selected plots around the seedlings, followed by controlled burning of the site early in the dry season to prevent more fierce and destructive fires later in the dry season, may be feasible. Existing seedlings can be protected by baskets while the protective burning is carried out.

A special threat to the regeneration of *P. merkusii* in Khong Chiam is grazing buffaloes. During the dry season, when the land is scorched and brown, the buffaloes mistake the grass stage of *P. merkusii* for fresh tufts of grass. The buffaloes bite off the top and destroy the seedling before spitting out the bitter tasting needles. Therefore, grass stage seedlings have to be protected from grazing buffaloes during the dry season. This could be done by fencing or by controlled grazing

schemes enabling regeneration, not only of *P. merkusii* but also of other tree species, in certain areas of the reserve. Most importantly, the destructive fire stick cutting will have to be brought to an end to protect the remaining mature trees until regeneration has taken place.

Another management measure to ensure regeneration is to collect seeds and raise them in the nursery to be planted out, once they have reached a competitive age. Facilities are already present at the conservation station at Khong Chiam.

For the other small and degraded *P. merkusii* stands in zone 8 *ex situ* conservation seems to be the only option to save the genetic material. Seed should be collected as soon as possible for the establishment of *ex situ* stands. Collection can be done source by source if sufficient mother trees are available, otherwise mixing of several sources is a means of saving gene pools on a basis of seed zones. It is recommended to sow the seed immediately after harvest as seed of the eastern provenances matures in the rainy season and is difficult to dry down sufficiently for storage.

Small quantities of seed from Khong Chiam, Non Khu, and Buntharik provenance are found in DFSC´s seed bank in Denmark. These seed lots could complement locally harvested seed in the establishment of *ex situ* stands.

7. SELECTION OF STANDS FOR ACTIVE CONSERVATION EFFORTS

The aim of a national conservation plan for a species is to conserve all major gene pools, while on the other hand limiting the number of conservation stands to a manageable level. The main criteria for selection of stands for which active conservation measures are recommended is the conservation status, the genetic and economic value of the stands and the resources available. The allocation of funds for conservation of a particular species is dependent on prioritisation at national level. In Thailand, a number of endangered hardwoods have high priority and indeed conservation efforts on a number of these are underway. Although not of high national priority at present, the importance of *P. merkusii* in a regional context should also be considered.

In view of the national potential as well as regional responsibility, it is recommended that conservation efforts in *P. merkusii* in Thailand be concentrated on the lowland stands of *P. merkusii*, which were found genetically distinct and furthermore performed best in provenance trials. These are first of all the stands at Khong Chiam and Non Khu in eastern Thailand. Furthermore the lowland stand at Pa Chum Chon in the southwest should be surveyed and sought conserved. All three stands are found in areas with heavy pressure from human activities and intensive conservation measures including the involvement of local people are considered necessary. *Ex situ* conservation should be considered as a complementary conservation strategy for all three stands and it might be the only realistic approach for the stand at Non Khu.

P. merkusii is not in immediate danger of disappearing from any of the other remaining zones. It is recommended, however, that the populations in the central, north and northwest are included in the conservation plan to be monitored. This forms part of the Forest Department's general responsibilities. Active conservation efforts should be initiated whenever found necessary. This is in no way meant to discourage general forest conservation efforts in the highlands, which are certainly appropriate and needed. In most cases, at least initially, it is suggested to rely on protected areas and forest reserves in these zones.

By focusing active conservation efforts on *P. merkusii* to the three lowland stands it becomes an affordable and manageable task to conserve the most valuable, genetically distinct and highly threatened Thai provenances of *P. merkusii*.

8. IMPLEMENTATION OF CONSERVATION ACTIVITIES

Implementation of the proposed 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. Contact to stakeholders including local communities
5. Decision of conservation measures to be taken (*in situ* or *ex situ*)
6. Demarcation and protection of *in situ* stands
7. Sampling and seed collection in populations for *ex situ* conservation
8. Establishment of *ex situ* conservation stands
9. Management of conservation stands (*in situ* and *ex situ*)
   - Management guidelines
   - Protection
   - Monitoring (inspection and assessment)
   - Tending

9. Current revision of long term planning

It is essential that planning and implementation are done in collaboration with local stakeholders. The activities are partly overlapping and some will reoccur. The first revision of the implementation schedule and budget should be made after the field survey has taken place and the specific conservation measures have been identified. An implementation schedule is shown in table 2.

8.1 Field surveys

The field surveys should involve inspection of the proposed sites plus additional remaining stands in zone 1 and 8. The inspection of potential *in situ* conservation stands involves mapping and preparation of reporting protocols. The field surveys should also result in the final selection of conservation measures to apply (*in situ* and/or *ex situ*).

8.2 Management and monitoring of *in situ* stands

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. The initial step towards the conservation plan for *P. merkusii* was assessment of a number of natural stands. The assessment focused on the size, stability and regeneration of the populations. Stands at Khong Chiam, Nong Krating, Phu Toei and Phu Kradeung were assessed. In addition, stands at Ban Wat Chan, Ta Yang, Mae Hong Song, and Non Khu were visited. The assessment methodology is described in a draft assessment manual (DFSC, 1997a) and the assessments are documented in assessment reports (DFSC 1997b, 1998a, 1998b, and 1999 – all unpublished). They will serve in support of developing stand-specific management guidelines for the conservation areas. Preparation of management guidelines for conservation stands is dealt with in more detail by Graudal *et al.* (1997). Specific management options are described in section 6.6. Management guidelines in zone 1 and 8, where there is high pressure on the stands from local people, should be developed in close collaboration with local stakeholders.

In situ stands should be demarcated and protected in collaboration with local stakeholders. Signboards with map and key figures should be put up. When tending is required, it should favour stability and regeneration. For some populations the conservation effort will consist of a certain management system. Where this is needed, it will mainly include control of fire, cutting of fire sticks, resin tapping, and animal grazing. In some cases enrichment planting should be considered.

In such cases the seedlings should be raised from seed collected locally.

Conservation efforts can be combined with different forms of sustainable utilisation. This would be the case for stands in community forests or managed nature reserves. In general, sustainable use of forest resources creates an incentive to conservation.

Monitoring will consist of regular inspections and, less frequently, more thorough field assessments. The local forest officers may make annual inspections as part of their ordinary services. If local communities are involved in the management, they should take part in the monitoring.

Assessment of selected areas has already been undertaken (DFSC 1997b, 1998a, 1998b and 1999). These assessments will contribute to the development of practical management guidelines for the conservation areas. The need for more thorough field assessments should be considered on an ad-hoc basis as part of the regular inspection.

Table 2. Long-term implementation schedule for conservation of the genetic resources of *P. merkusii* in Thailand.

Activity\Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Planning											
Long-term incl. budget	x				x					x	
Annual reporting, budget	x	x	x	x	x	x	x	x	x	x	x
Implementation											
Surveys (zone 1, 5, 8)	x										
Selection of stands	x	x									
Selection of conservation measures	x	x									
In situ conservation											
Management guidelines		x									
Monitoring, all zones (local office)		x	x	x	x	x	x	x	x	x	x
Active measures (zone 1, 2 and 8)		x	x	x	x	x	x	x	x	x	x
Assessment (zone 1, 2 and 8)					x					x	
Ex situ conservation (zone1, 8)											
Survey of existing populations	x										
Ex situ management guidelines		x	x								
Seed collection and planting		x	x								
Stand establishment			x	x							
Maintenance			x	x	x	x	x	x	x	x	x
Thinning											x

8.3 Establishment and management of ex *situ* stands

Selected stands subject to a high degree of threat should be complemented by conservation *ex situ*. Seed collection should follow the overall guidelines given in section 6.2. It is recommended to sow the seeds immediately after harvest as seeds of the eastern provenances mature in the rainy season and are difficult to dry sufficiently for storage. The *ex situ* stands being established should consist of 1500 individuals at rotation age, i.e. around 5-15 ha per stand or approximately 30-100 rai per stand. The stands must be outside the range of other contaminating pollen sources.

Monitoring of *ex situ* stands is in principle the same as for the *in situ* areas. In practice there are, however, important differences. *Ex situ* stands will in general be located on better protected sites - in the case of *P. merkusii* most likely next to the already established gene conservation stations. Fencing around the stands may be necessary in the first years after establishment. Hereafter, stands will require general plantation management. Tending during the first five years will consist of weeding, fertiliser application and fire control. The first thinning is expected to take place 10 years after establishment. Thinning should in principle support naturally selective forces and may therefore not be purely systematic. 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. CONCLUSION

This conservation plan for *P. merkusii* in Thailand documents present status of the species and proposes demarcation of a number of conservation areas in order to maintain the genetic variation within the species. The plan is largely based on an assessment of the following three questions: (i) what is the conservation status of the different occurrences of *P. merkusii;* (ii) how is the genetic variation of *P. merkusii* distributed and (iii) which areas should actively be managed for genetic resource conservation?

The conservation status of *P. merkusii* in Thailand was assessed based on knowledge of past and present distribution, regeneration, present utilisation and threats indicating the protection status of the species. The major part of the extensive northern and northeastern populations are found within forest reserves or protected areas. This gives the stands good legislative protection and their conservation status is generally good. In contrast, all of the lowland stands within Thailand are within areas of high human pressure and found to be threatened.

The aim of a conservation plan for a target species is to conserve all major gene pools. Therefore reliable information on the genetic variation and variation patterns is important in order to establish an effective network of conservation stands. The genetic variation of *P. merkusii* in Thailand was assessed using available information from already existing provenance trials as well as inferred from its distribution within different ecological zones assuming that similarity of ecological conditions implies similarity of genetic constitution.

Eight genecological zones were delineated. Genecological zones are areas of uniform ecological conditions and subject to none or limited gene flow from surrounding areas. Such zonation is a practical tool in selection of populations to be conserved. For *P. merkusii* in Thailand, it was found from provenance testing that the southwestern and eastern lowland provenances differ significantly from the rest. In field trials these provenances performed most promisingly in regard to growth and volume production. Minor differences were observed among populations in the north and northeast.

While aiming at conserving all major gene pools, there is a practical need to limit the number of conservation stands to a manageable level. The main criteria for selection of stands for which active

conservation measures are recommended are conservation status and the genetic and socio-economic value. Institutional capabilities and resources available will finally have a major influence on the number of selected of stands.

The allocation of funds for conservation of a particular species is dependent on prioritisation. Thailand has a large number of important forest tree species, many of them endangered, and only limited resources for conservation. A number of threatened hardwood species are considered by Royal Forest Department to have high priority, and conservation efforts for a number of these are already underway. Although *P. merkusii* is not considered of high national priority at present it could potentially be of importance in the future, both in Thailand and in other tropical countries where it is already widely used in plantations.

It is recommended that conservation efforts in *P. merkusii* in Thailand be concentrated on the highly endangered lowland stands of *P. merkusii*, which were found genetically distinct and which also performed well in provenance trials. These include the stands at Khong Chiam and Non Khu in eastern Thailand where conservation areas have already been demarcated. Furthermore, the lowland stand at Pa Chum Chon in the southwest should be surveyed and action taken to ensure its conservation. All three stands mentioned are found in areas with heavy pressure from human activities, and intensive conservation measures, including the involvement of local people, are necessary.

P. merkusii is not in immediate danger of disappearing from any of the remaining zones. It is recommended, however, that the populations in the central, north and northeast are included in the overall national conservation plan; and that the conservation status of the stands be monitored, and active conservation efforts be initiated whenever found necessary. By focusing active and more intensive conservation efforts in *P. merkusii* to the lowland stands, action becomes affordable and manageable, also in the long term.

The present study shows that the early attempts to conserve the genetic resources of *P. merkusii* were far-sighted in the sense that priorities were established focusing on the most valuable and most threatened occurrences in the low-lands of north-eastern Thailand. Nonetheless, the conservation efforts in the lowland areas so far have proved to be inadequate, mainly due to insufficient involvement of the local communities (Granhof 1998). The Royal Forest Department is in favour of including such aspects as an integral part of future conservation activities (Sumantakul and Granhof, 2000). It is hoped that a strategy based on strong community participation will enable conservation of the remaining lowland provenances of *P. merkusii* in Thailand.

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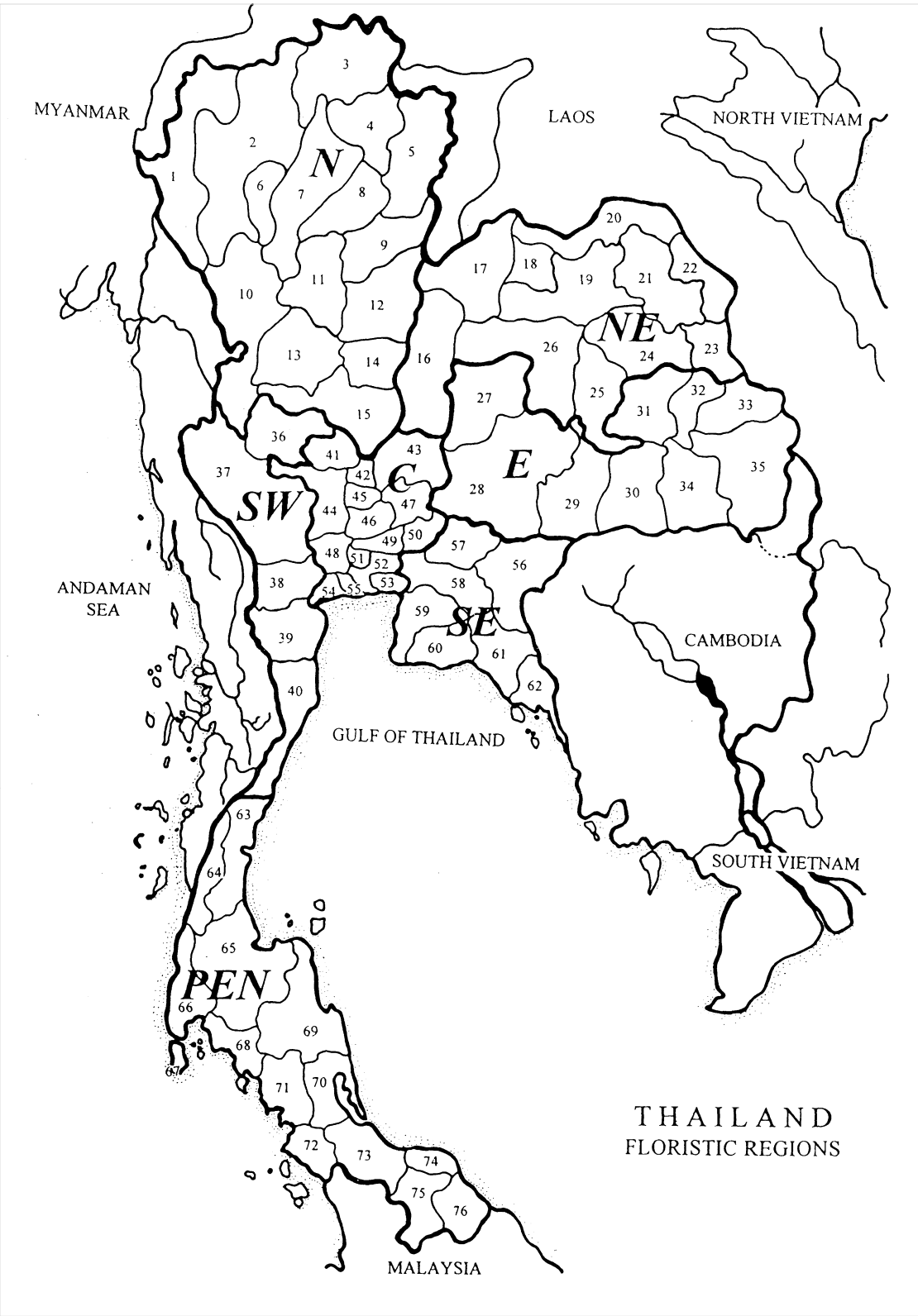
Appendix 1. Floristic regions and provinces in Thailand (Flora of Thailand 7(1) 1999)



FLORISTIC REGIONS AND PROVINCES OF THAILAND

I. *N* (NORTHERN)
- 1 Mae Hong Son
- 2 Chiang Mai
- 3 Chiang Rai
- 4 Phayao
- 5 Nan
- 6 Lamphun
- 7 Lampang
- 8 Phrae
- 9 Uttaradit
- 10 Tak
- 11 Sukhothai
- 12 Phitsanulok
- 13 Kamphaeng Phet
- 14 Phichit
- 15 Nakhon Sawan

II. *NE* (NORTH-EASTERN)
- 16 Phetchabun
- 17 Loei
- 18 Nong Bua Lum Phu
- 19 Udon Thani
- 20 Nong Khai
- 21 Sakon Nakhon
- 22 Nakhon Phanom
- 23 Mukdahan
- 24 Kalasin
- 25 Maha Sarakham
- 26 Khon Kaen

III. *E* (EASTERN)
- 27 Chaiyaphum
- 28 Nakhon Ratchasima
- 29 Buri Ram
- 30 Surin
- 31 Roi Et
- 32 Yasothon
- 33 Amnat Charoen
- 34 Si Sa Ket
- 35 Ubon Ratchathani

IV. *SW* (SOUTH-WESTERN)
- 36 Uthai Thani
- 37 Kanchanaburi
- 38 Ratchaburi
- 39 Phetchaburi
- 40 Prachuap Khiri Khan

V. *C* (CENTRAL)
- 41 Chai Nat
- 42 Sing Buri
- 43 Lop Buri
- 44 Suphan Buri
- 45 Ang Thong
- 46 Phra Nakhon Si Ayutthaya
- 47 Saraburi
- 48 Nakhon Pathom
- 49 Pathum Thani
- 50 Nakhon Nayok
- 51 Nonthaburi
- 52 Krung Thep Maha Nakhon (Bangkok)
- 53 Samut Prakan
- 54 Samut Songkhram
- 55 Samut Sakhon

VI. *SE* (SOUTH-EASTERN)
- 56 Sa Kaeo
- 57 Prachin Buri
- 58 Chachoengsao
- 59 Chon Buri
- 60 Rayong
- 61 Chanthaburi
- 62 Trat

VII. *PEN* (PENINSULAR)
- 63 Chumphon
- 64 Ranong
- 65 Surat Thani
- 66 Phangnga
- 67 Phuket
- 68 Krabi
- 69 Nakhon Si Thammarat
- 70 Phatthalung
- 71 Trang
- 72 Satun
- 73 Songkhla
- 74 Pattani
- 75 Yala
- 76 Narathiwat

Appendix 2. List of major P. merkusii locations in Thailand and their protection status (mainly after Werner 1993).

Region	Geneco-logical zone	Location	District	Province	Lat.	Long.	Altitude (m)	Size (ha)	Conservation status
SW	1	Pha Chum Chon	Tha Yang	Phetchaburi	12°50	99°47	70-170	51	Protected forest. Stand very small and disappearing. Less than 300 trees. Cutting of fire-sticks.
SW	1	Khao Maa Lai	Tha Yang	Phetchaburi	12°75	99°45	220-250		Less than 10 trees. Stand disappearing. Resin tapping practiced.
SW	1	Khao Son	Tha Yang	Phetchaburi	12°60	99°37	250-400		Stand very small and disappearing
C	2	Phu Toei	Daan Chant	Suphan Buri	14°59	99°26	600	200	National Park. Poor regeneration. May be due to annual fires. >3000 trees.
N	3a	20 km east of Mae Sod	Mae Sod	Tak	16°43	98°49	450		On gravelly ridges as small groups of almost 30 m tall, emergent trees over poor dry Dipterocarps.
N	3a	Phop Phra	Phop Phra	Tak	16°23	98°43	430-450		*P. merkusi*i found on gravelly ridges. Trees 25-27 m tall.
N	3b	Omkoi Plateau	Omkoi	Chiang Mai	17°30-17°80	98°17-98°35	850-1080		Forest reserve. Largest stand in Thailand, 50 km N-S. Mixed with *P. kesiya*. Good regeneration, young trees.
N	3b	Ban Huey Bong	Hod	Chiang Mai	18°10	98°25	800		Huey Bong Pine Improvement centre. Ex situ conserva-tion of pines.
N	3b	Baw Luang	Hod	Chiang Mai	18°10	98°20	850-950		Baw Luang plateau was afforested with *P. kesiya* in the Thai Danish project around 30 years ago. A few *P. merkusii*.
N	3c	Doi Phra Luang		Tak	17°27	99°13	700		Plateau at 700 m alt. *P. merkusii* at the edge and in broad leaf forest below. Some 44 m. tall and 120 cm diameter. Third tallest trees in Northern Thailand only superseded by those in Thung Salaeng Luang and Doi Mae Tai.
N	4	Khun Yuam	Khun Yuam	Mae Hong Son	18°50	97°56	600		Reserved Forest. Extensive stand.
N	4	Rd. Mae Hon Son to Pai	Pai	Mae Hong Son	19°22	98°24	500-750		3 stands along road. Intensive resin tapping.
N	5	Doi Khun Tan	Mae Tha	Lamphun	18°30	99°16	7-950		National Park. Pine-dipterocarp-oak forest
N	5	Mae Om Long	Hod	Chiang Mai	18°30	98°25	1050		Mixed with *P. kesiya.*
N	5	Mae Win	San Pa Tong	Chiang Mai	18°30	98°35	800		Pine-dipterocarp-oak forest
N	5	Huey Tong	San Pa Tong	Chiang Mai	18°30	98°35	800		Pine-dipterocarp-oak forest
N	5	Doi Inthanon	Chomtong	Chiang Mai	18°41	98°27	1000-1100		National Park. Mixed with *P. kesiya.*
N	5	Doi Suthep	Muang	Chiang Mai	18°80	98°90	1200		National Park. In evergreen forest. In danger of extinction.
N	5	Doi Saket	Doi Saket	Chiang Mai	18°85	99°12	400		Probably disappeared.
N	5	Samoeng	Samoeng	Chiang Mai	19°00	98°45	1100		
N	5	Khung Lao	Wieng Pa Pao	Chiang Rai	19°02	99°20	780		
N	5	Phayao	Phayao	Phayao	19°04	99°50	850		
N	5	Ban Wat Chan	Mae Cham	Chiang Mai	19°05	98°18	900		Third largest area with *P. merkusii*. Villagers involved in conservation of community forest.

N	5	Phrao	Phrao	Chiang Mai	19°06	99°01			
N	5	Khun Kong	Chieng Dao	Chiang Mai	19°19	98°49	1000		Mixed with *P. kesiya.*
N	5	Nong Kiew		Mae Hong Son	19°00	98°07	1100		Mixed with *P. kesiya*.
N	5	Doi Chiang Dao	Chiang Dao	Chiang Mai	19°25	98°50	9-1100		Wildlife reserve. Pine-dipterocarp-oak forest. Rare.
N	5	Doi Mae Tae		Chiang Mai	19°32	98°45	700		45-52 m tall, dominates less tall broad-leaves. Second tallest trees in Thailand.
N	5	Wiang Haeng	Wiang Haeng	Chiang Mai	19°35	98°39	1100		Mixed with broad-leaves.
N	5	Rd. Wiang Haeng to Ban Na Tai	Muang	Chiang Mai	19°44	98°46	900		All *P. merkusii* are tapped for resin. Up to 40 m tall, mixed with broad-leaves.
N	5	Mae Suey (Suai)	Mae Suey	Chiang Rai	19°42	99°35	680		
N	5	Fang	Fang	Chiang Mai	19°52	99°15	600		
N	6	Doi Phu Kha	Pua	Nan	19°30	101°00	730		National Park.
N	6	Doi Phu Huat		Nan	18°90	101°10	690-930		Population size unknown.
N	7a	Thung Nang	Phaya	Phitsanulok	16°33	100°47			
N	7a	Thung Salaeng Luang	Lom Sak	Phitsanulok	16°34	100°47	700-900		National Park. Seed source. Last seed coll. 1987. 60 m tall. Annual fires. Re-generation status unknown.
NE	7b	Nam Nao	Lom Kao	Petchabun	16°40	101°33	800		National Park. Seed source collected for provenance tri als + plantation in 1973. Split into smaller stands due to shifting cultivation. Regeneration status unknown. Mixed with kesiya and broad-leaves.
NE	7b	Phu Kradeung	Phu Kradeung	Loei	16°53	101°53	1300		National Park. Large plateau with *P. merkusii*-savanna. Regeneration impeded by annual fires but population in no immediate danger of extinction.
NE	7b	Phu Rua	Phu Rua	Loei	17°30	101°19	1050-1300		National Park. Plateau with pine-savanna. Status unknown.
NE	7b	Phu Kieo	Khon San	Chayapum	16°20	101°40	850-950		Wildlife Reserve. Plateau with Pine-Savanna. *P. merkusii* absent according to Werner (1993).
NE	7b	Phu Luang	Phu Luang	Loei	17°15	101°52	1200		Wildlife Reserve. Plateau with Pine-savanna.
E	8	Non Khu	Sangkha	Surin	14°43	103°50	180		In situ conservation stand. Poor regeneration <1000 trees.
E	8	Buntharik	Buntharik	Ubon Ratchatani	14°45	105°25	140-150	0 ?	Proposed conservation area was never established. In 1993 the stand covered an estimated 1000 ha but was declining due to resin tapping and encroachment. Present status unknown. Population might be extinct.
E	8	Kantharome	Kantharome	Si Sa Ket	14°10	104°70	160		Stand declining < 100 trees.
E	8	Khong Chiam	Khong Chiam	Ubon Ratchatani	15°30	105°30	130-160	1000	In situ conservation stand <3000 trees. Intensive use of forest by locals. Poor regeneration mainly due to annual fires. Stand declining.
E	8	Dong Na Than	Khong Chiam	Ubon Ratchatani	15°60	105°50	400-440		Less than 100 trees
E	8	Po Sai	Po Sai	Ubon Ratchatani	15°80	105°30	130-140		Forest Reserve. Less than 100 trees

This list is not a complete list of *P. merkusii* in Thailand. The exact location of stands (longitude and latitude) may deviate from those stated here.